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NEW YORK-NEW JERSEY AIR POLLUTION ABATEMENT ACTIVITY, SULFUR COMPOUNDS AND CARBON MONOXIDE

National Center for Air Pollution Control
Cincinnati, Ohio

January 1967

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-- Errata Sheet --

Corrections

1. Pages 39 & 40 - Tables on these two pages should be reversed.

2. Pages 53, 54 and 55 - the legend for Figures 20, 21, and 22 should read -- SO_x Density tons/day per mi^2; these figures as well as figure 19 should precede the section on discussion of carbon monoxide.

3. Page 56 - The legend for Figure 23 should read - CO Density, Tons/day per mi^2; also Point Sources emitting >10 should be changed to Point Sources emitting large quantities.

4. Page 73 - Figure 40 - The U in this figure should be a $\bar{U}$.

5. Page 83 - Table XXXV should appear in the section on carbon monoxide, immediately preceding discussion of Sulfur Dioxide.

6. Page 84 - The word Forward on this page should be changed to Foreword.

7. Page 96 - Include New Rochelle and Central Park in the first sentence of the last paragraph.

8. Pages 166-172 - These pollution roses are all based on hourly data.

9. Page 104 - Under heading "SO_2 Transport Rate" - "n" should be "N".

10. Page 122 - Under heading "Point Sources", insert before the number "0.575" the following group of words "1.875 percent, 2,350,000 gallons of distillate oil with a sulfur content of".

11. Page 123 - Second paragraph under heading "Residential Use of Oil - New Jersey" - Delete the second group of words "it was possible to".

12. Page 124 - Heading should read "Industrial Fuel Use in New Jersey" instead of "Industrial Fuel Use in New York City".

13. Page 125 - Under paragraph entitled "Homogenous Commercial and Governmental Fuel", delete the "e" in the spelling of Pohrman, et al.

PB 230 345

TECHNICAL REPORT

NEW YORK—NEW JERSEY
AIR POLLUTION ABATEMENT ACTIVITY

Sulfur Compounds and Carbon Monoxide

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
National Center
for Air Pollution Control
Cincinnati, Ohio
1967

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NEW YORK-NEW JERSEY AIR POLLUTION ABATEMENT ACTIVITY

SULFUR COMPOUNDS AND CARBON MONOXIDE

SECTION I—SUMMARY AND CONCLUSIONS

A technical investigation of air pollution in the New York-New Jersey metropolitan area was conducted during the summer of 1966. The survey area includes 17 counties, 8 in New York and 9 in New Jersey. The population of the area is more than 15 million persons.

The air quality survey of this investigation included measurements of sulfur compounds and carbon monoxide. Sulfur dioxide was monitored at 15 stations; combined data from all stations show that for 895 station-days a daily average concentration of 0.1 part SO_2 per million parts of air was exceeded 27 percent of the time during the period June through August. Carbon monoxide was monitored at nine of these stations. The average value for 15,700 hourly observations was approximately 5 parts CO per million parts of air. In-traffic samples obtained with a mobile monitoring unit in congested areas during hours of heavy traffic yielded concentrations greater than 33 parts of CO per million parts of air more than 50 percent of the time.

An inventory of emissions of sulfurous gases and carbon monoxide was made. More than 1,590,000 tons of sulfurous pollutants, 97 percent of which is sulfur dioxide, are emitted each year from sources in the survey area. Approximately half of this total is emitted from sources in New York, and half from sources in New Jersey. Almost 5,300,000 tons of carbon monoxide are emitted annually in the survey area. More than 95 percent of this total is generated by gasoline-fueled motor vehicles.

Meteorological measurements made in the course of this investigation, and records of past meteorological conditions, show winds from all directions and the movement of polluted air from either State to the other. Past tracer studies illustrate interstate movement. Combinations of air monitoring, meteorologic, and emissions data were used to estimate quantities of sulfur dioxide that moved interstate during specific periods of time.

Results of this investigation lead to the conclusions:

1. Sulfur dioxide air pollution endangers the health and welfare of persons in the New York-New Jersey metropolitan area. Concentrations of sulfur dioxide measured during the summer season exceeded air quality objectives; concentrations are greater during the winter season than in the summer.

2. Sulfur dioxide air pollution is interstate in character in the New York-New Jersey metropolitan area. This pollutant is generated in approximately equal quantities in the two States and is

discharged into the air supply common to the metropolitan area. Depending upon wind direction, sulfur dioxide generated in either State is transported to the other without regard to state boundaries.

3. Carbon monoxide air pollution in congested areas at times of high traffic density represents a potential hazard to the health and welfare of persons exposed over extended periods of time. Cumulative exposures in heavy traffic areas probably exceed tentative objectives of the State of New York. Concentrations of carbon monoxide observed at fixed monitoring sites in the survey area did not exceed the tentative air quality objectives of the State of New York. The observed levels bordered on those that cause impairment of mental processes, however, and may be near the level needed to protect persons suffering cardiac, respiratory, or anemic impairment. Federal regulations on control of emissions from automobiles will result in a decrease in emissions of carbon monoxide in the metropolitan area over the next decade.

SECTION II—INTRODUCTION

During the summer of 1966, the Department of Health, Education, and Welfare coordinated a technical investigation in the New York-New Jersey metropolitan area to provide information that could form a basis for the first of a series of public conferences under Section 105 of the Clean Air Act, as amended (42 USC 1857, et seq). Abatement of interstate air pollution is the ultimate goal of such conferences; they will provide information on which the Secretary of Health, Education, and Welfare can base recommendations for abatement in accordance with the tenets of the Clean Air Act.

As required by the Clean Air Act, the New York State Air Pollution Control Board and the New Jersey State Department of Health were invited to participate in the technical investigations -- which they readily agreed to do. Additional technical support was requested of and provided by the Interstate Sanitation Commission, the City of New York, New York University, and a number of local agencies in New York and New Jersey.

Many air pollution surveys have been conducted in this region over the past several years. The most pertinent of these are summarized, and their results are utilized wherever possible.

This report presents the results of the 1966 investigation and describes the methods, the techniques, and the procedures followed. In concert with the cooperative agencies, an air quality network was established, an emissions inventory was conducted, extensive meteorological data were acquired, air pollution effects on vegetation and various materials were investigated, and special data processing and summarization techniques were developed.

Tabulations of the basic data were forwarded to all cooperating agencies. The evaluation and correlation of results presented in this report reflect the scientific and technical judgment of the personnel of the National Center for Air Pollution Control, Public Health Service, U.S. Department of Health, Education, and Welfare.

HISTORY OF ABATEMENT ACTION

For at least six decades, it has been alleged that interstate air pollution is an important factor in the New York metropolitan area. Emphasis was placed particularly on pollution of Staten Island, New York, by sources located in New Jersey. Over the years, many studies and investigations into the medical, engineering, agricultural, economic, esthetic, nuisance, legal, and other aspects of the problem have been undertaken by government agencies at all levels, by citizen organizations, and by universities, industrial concerns, consultants, and private institutions. The more pertinent of these surveys, particularly those of a technical nature, are summarized elsewhere in this report and need not be cited here. It may merely be noted that an assortment of investigations, both objective and subjective in character, between 1931 and 1955, confirmed that air pollution originating in New Jersey had a demonstrable effect on Staten Island and Manhattan, New York.

Legal means for coping with the problem were evaluated in several of these investigations. In each case, it was concluded that existing legislation was inadequate insofar as it related to ameliorating the difficulties related to interstate air pollution.

After at least 5 years of negotiation, legislative action was taken in Connecticut, New Jersey, and New York, and Congressional consent was given in 1956 authorizing and empowering the Interstate Sanitation Commission to make a comprehensive study of smoke and air pollution in the New York-New Jersey area. In essence, the commission was charged with determining whether interstate air pollution existed and, if so, with submitting recommendations for legislative and administrative solutions.

In 1957, the Public Health Service and other Federal agencies, with the active participation and assistance of a variety of State and local organizations, cooperated with the Interstate Sanitation Commission in conducting a survey of the problem. In addition to conducting a technical investigation, current air pollution legislation was evaluated. The official report recommended that an interstate instrumentality be created. In 1959, the Interstate Sanitation Commission submitted to the legislatures of New York and New Jersey proposed legislation to implement that recommendation. The original proposal was not enacted into law but, in 1961, compromise legislation evolved. The Interstate Sanitation Commission was thereby authorized to engage in research, testing, and studies in the New York metropolitan area to identify sources of interstate air pollution. For abatement action, however, it was necessary for the Commission to refer complaints and information on the sources of interstate air pollution to the appropriate State agency.

During that period, Federal air pollution legislation made no provision for abatement action. On December 17, 1963, however, President Johnson signed the Clean Air Act (Public Law 88-206), which replaces previous Federal legislation in the air pollution field. One of the principal provisions of this Act authorizes the Department of Health, Education, and Welfare to engage directly in abatement activities when the health or welfare of the citizens of one State is endangered by air pollution discharged in another State.

The new Act, like the Federal air pollution legislation it replaced, recognizes that the primary responsibility for the regulatory control of air pollution rests with local government and with the States. For the first time, however, the Federal government was authorized to take abatement action.

On July 8, 1964, Congressman John M. Murphy wrote the Secretary of Health, Education, and Welfare Anthony Celebrezze, claiming that air pollution from New Jersey was endangering the health and welfare of residents of portions of New York City, and requesting appropriate action be taken under provisions of the new Clean Air Act. Based primarily on this request, the Secretary called for a consultation, which was conducted in New York City on August 18, 1964. The consultation involved representatives of the air pollution control agencies of the States of New Jersey and New York, the Interstate Sanitation Commission, and the Public Health Service. The results of this consultation were not, in all aspects, conclusive; however, the consensus of the State and interstate agencies was that an air pollution abatement conference was not necessary.

Following the consultation, the Department of Health, Education, and Welfare evaluated data submitted by the State of New Jersey, the City of New York, and the Interstate Sanitation Commission. The evaluation indicated that surveillance should be continued to provide the Secretary with a basis for determining whether further Federal action, under the Clean Air Act, should be taken.

Accordingly, an air sampling program was conducted in Staten Island and adjacent portions of New Jersey during the summer of 1965.

Before the results of this survey could be thoroughly analyzed and placed into context with information already available, overriding official action occurred.

On October 15, 1965, Governor Nelson A. Rockefeller of New York requested that the Secretary of Health, Education, and Welfare call a conference under provisions of subsection 105 (c) (1) (A) of the Clean Air Act, regarding the matter of air pollution discharged in the State of New Jersey alleged to endanger health and welfare of persons in the State of New York.

In his November 5, 1965, reply, Secretary John W. Gardner indicated that he would call a conference (mandatory under the Act when requested by a Governor). He pointed out, however, that the characteristics of the New York-New Jersey metropolitan area indicate that consideration should also be given to air pollution originating in New York that might endanger health and welfare of persons in New Jersey. Governor Richard J. Hughes of the State of New Jersey also was advised of this action, which invoked subsection 105 (c) (1) (C) of the Act.

Following these steps, a series of consultations was held between representatives of the Department of Health, Education, and Welfare, the New York State Air Pollution Control Board and the New Jersey State Department of Health. During the course of these consultations, several factors were resolved:

1. The extent of the geographic area to be included.

2. The manner in which the total interstate air pollution problem could be divided into segments for consideration in a series of abatement conferences.

3. The assignment of personnel and equipment for preliminary technical investigations.

The geographic area was selected primarily on a basis that would facilitate gathering and defining appropriate data. This area comprised Bergen, Essex, Hudson, Middlesex, Monmouth, Morris, Passaic, Somerset, and Union counties in the State of New Jersey; and the five counties of New York City, as well as the counties of Nassau, Rockland, and Westchester in the State of New York. It was agreed that the first abatement conference would be concerned with sulfur compounds and carbon monoxide, and that subsequent conferences would relate to other pollutants to be selected by mutual agreement.

It was further decided that special cooperative investigations by Federal, state, interstate, and local agencies would precede each conference to gather and evaluate data on the scope, sources, effects, interstate movement, and other aspects of the problem. Both states agreed to provide, under their respective laws, access to private property for tests and investigations by Federal personnel.

Personnel and equipment allocations were made, and the activity entered the detailed, technical investigatory phases, which are described more fully in subsequent sections of this report.

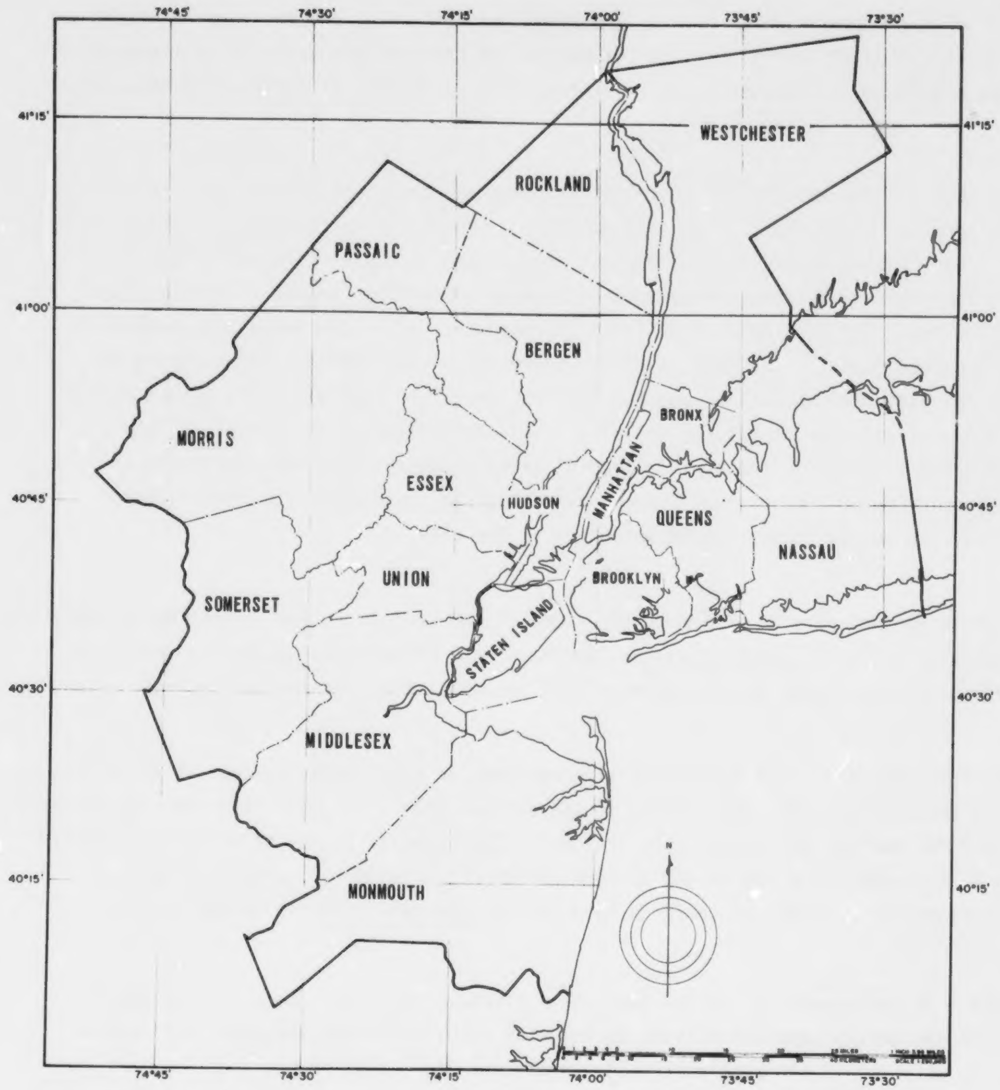
DESCRIPTION OF STUDY AREA

The geographic area for the abatement action comprises 17 counties in the two states (Figure 1). Widely diverse in population density, land use, industrialization, and economic activities, this is the most populous metropolitan area in the Nation.

The topography of the area has influenced the pattern of development of the region, and several topographic features significantly affect the distribution of air pollutants.

The southern and eastern portions of the region that border the Atlantic Ocean and Lower New York and Raritan Bays are coastal plain. The barrier beaches on the water proper are separated from the mainland by tidal marshes. The western and northern portions of the area are made up of a series of ridges, oriented mostly northeast-southwest, which are a part of the Appalachians. In the extreme northern and western portion, in the Bear Mountain and New Jersey Highlands area elevations average well over 1,000 feet above sea level with peaks about 1,400 feet. From the Highlands eastward, the series of essentially parallel ridges becomes progressively lower until the easternmost in New Jersey, the Hudson Palisades, is reached. This ridge, which generally is about 300 feet high, rises sharply to 500 feet above the Hudson River in places. It extends from the northern edge of the area southward to Jersey City. The 600-foot Watchung Range lies roughly parallel to and 10 to 15 miles west of the Palisades. Between the Palisades and the Watchung Range lie the low, marshy New Jersey Meadows. This lowland area, through which the Passaic and Hackensack Rivers meander before emptying into Newark Bay, extends southward to Raritan Bay and northward into Rockland County.

The Hudson River flows through the study area from north to south. Except for Rockland County, New York, which borders Bergen County, New Jersey, the New York counties are separated from New Jersey by the Hudson River, New York Harbor, Kill van Kull, and Arthur Kill. In addition, numerous other bodies of water separate much of the area from the mainland. The western end of Long Island Sound separates the mainland Bronx and Westchester Counties from Long Island on which are located Brooklyn, Queens, and Nassau. Manhattan Island, whose west side flanks the Hudson River, is separated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BERGEN
BRONX
MORRIS
ESSEX
HUDSON
MANHATTAN
QUEENS
NASSAU
UNION
BROOKLYN
SOMERSET
STATEN ISLAND
MIDDLESEX
MONMOUTH
N

Figure 1. New York-New Jersey Air Pollution Abatement Activity area.

from the New York mainland by the tidal Harlem River and from Long Island by the East River. With the exception of the Raritan River, which flows easterly across the southern portion of the area and empties into Raritan Bay, the major rivers, valleys, and ridges are oriented approximately north-south or northeast-southwest.

The tall buildings of Manhattan Island and the increasing number of high-rise apartments and office buildings being constructed on the higher ground of the metropolitan area tend to accent the basic north-south orientation of the natural topographic features.

Bounded by the ocean to the southeast and low mountains to the northwest, the metropolitan area tends to sprawl to the northeast and southwest. Because the direction of growth of the metropolis and the orientation of major topographic features are along the same axis, and the terrain often tends to channel the air flow along this axis during periods of high concentrations of pollutants, the terrain must be considered in assessing the significance of variations of air quality throughout the area.

The concentrations and characteristics of industry, commerce, and population in an urban area are significant factors in the etiology of its air pollution. By almost any measure of commerce and industry, the urban complex comprising the project area is the largest in the United States. It is the nation's leading manufacturing center; approximately 1.9 million people in the area are employed in manufacturing. The area leads the nation in commerce. It is the largest wholesale trade center in the United States. The area is within overnight surface transportation range of some 30 percent of the nation's population, and New York Harbor is the busiest in the United States with some 25,000 ship arrivals and departures annually. The combination of ship, surface, and air transportation makes New York one of the world's leading traffic centers for both international and domestic passenger travel. The presence of the United Nations headquarters and facilities, among other features, frequently focuses world attention on the city.

New York is the financial capital of the world. Some of the world's largest banks, trust companies, and clearing houses are located in the city as are leading stock, produce, and commodity exchanges. It is headquarters for a huge number of the nation's most important business and professional enterprises.

According to 1965 estimates, more than 15 million persons, or about eight percent of the nation's population, live in the nearly 3,500 square miles of the project area. The population density for the entire area is 4,410 persons per square mile (Table I). The density ranges from a high of 77,270 in Manhattan (New York County) to a low of 580 in Somerset County, New Jersey. The density for the eight New York counties is 8,590, as compared to 2,140 for the nine counties in New Jersey.

About 60 percent of the population of New York State lives in the eight counties, and about three-fourths of the New Jersey population lives in the nine counties of the abatement action area. Most of the area's population is strikingly oriented toward New York City; the bulk of New Jersey's population is located within 15 miles of Manhattan. Thus, in New Jersey, population densities ranging up to 30,000 persons per square mile are found in a relatively narrow band along the state line across from New York City.

The somewhat differing nature of the two states is apparent from the statistics in Table II. The population of the eight New York counties is 2.2 times greater than that of the nine New Jersey counties, whereas the number of households is 2.4 times greater. The number of employees in all categories, however, is 2.6 times greater, indicating that several areas of New Jersey, notably Bergen County, provide a place of residence for workers commuting to Manhattan. Another difference of importance to the air pollution aspects of the project area is the fact that passenger car registrations in the New York portion are only 1.3 times greater than those in the New Jersey portion. In fact, the number of persons per vehicle in the New York counties is nearly twice that in the New Jersey counties.

TABLE I
LAND AREA AND POPULATION DATA ON STUDY AREA

County	Land Area, mi^2	Population Jan. 1, 1965 (estimated)	Population Density, persons/mi^2
Bronx	43	1,450,000	33,720
Kings	76	2,650,000	34,870
Nassau	300	1,413,000	4,710
New York	22	1,700,000	77,270
Queens	113	2,025,000	17,920
Richmond	60	255,000	4,250
Rockland	178	180,000	1,101
Westchester	435	865,000	1,990
New York subtotal	1,227	10,538,000	8,590
Bergen	233	872,000	3,740
Essex	128	944,000	7,370
Hudson	45	601,000	13,360
Middlesex	312	530,000	1,700
Monmouth	477	411,000	860
Morris	467	320,000	690
Passaic	194	445,000	2,290
Somerset	307	177,000	580
Union	103	554,000	5,380
New Jersey subtotal	2,266	4,854,000	2,140
Grand total	3,493	15,392,000	4,410

TABLE II
COMPARISON OF CENSUS DATA ON NEW YORK AND NEW JERSEY STUDY AREA

	New York Portion of Study Area	New Jersey Portion of Study Area	Ratio NY/NJ
Population, January 1, 1965 (estimated)	10,538,000	4,854,000	2.2
Number of households January 1, 1965 (estimated)	3,433,600	1,418,900	2.4
Number of employees, 1964	3,615,609	1,365,186	2.6
Passenger car registrations, 1964	2,463,038	1,846,680	1.3

These brief statistics do not permit a quantitative determination, but they provide some indication of the air pollution potential of the area as a whole, and a comparison of the areas in the two separate states.

CLIMATOLOGY

There are six weather parameters that are normally used to estimate the relationship of climatology to an area's air pollution: wind speed, wind direction, turbulence, precipitation, temperature, and stagnation of anticyclones. The first three are basic parameters used to estimate the rate of diffusion of atmospheric pollutants. The latter three do not apply so directly. Each factor will be discussed in turn.

Concentrations of air pollutants are inversely related to wind speed. New York is a windy city. Considerable variation in the mean annual hourly wind speed occurs among the four U.S. Weather Bureau stations in the New York Metropolitan Area. The differences are a consequence of variations in surrounding terrain, and exposure and height above ground of the wind sensors. The mean speed at Central Park in the heart of Manhattan, the station with the lowest annual mean speed, is 9.7 mph. Table III lists mean speeds for the year and for the months with greatest and lowest average speeds.

TABLE III. MEAN HOURLY WIND SPEED AT NEW YORK METROPOLITAN AREA
U.S. WEATHER BUREAU STATIONS (mph)

	March	August	Annual
Central Park[a]	11.3	7.9	9.7
LaGuardia Airport[b]	15.5	10.5	12.9
J.F. Kennedy Int'l. Airport[c]	14.1	10.1	12.0
Newark Airport[d]	11.9	8.4	9.8

[a] Reference 1. [b] Reference 2. [c] Reference 3. [d] Reference 4.

More than half of the U.S. Weather Bureau stations on the mainland United States have a lower mean annual hourly speed than the station at Central Park. LaGuardia Airport has a higher mean annual hourly wind speed than that recorded at 90 percent of the U.S. Weather Bureau stations.

Further, the frequency of calms is low. Newark and LaGuardia Airports annually experience calms 1 percent of the time and J.F. Kennedy International Airport, 2 percent of the time. None of these stations normally experience calms more than 2 percent of the time during any month. By comparison, calms occur at National Airport, Washington, D.C. 5 percent of the time annually and 7 percent of the time during November.[5]

Concentrations of air pollutants vary as wind directions change. As wind directions vary, the sources originally pertinent to a receptor are replaced by other sources different both in number and in rates of emission.

Annual and summer wind roses showing the distribution of wind directions at LaGuardia, J.F. Kennedy International, and Newark Airports, and at Central Park are presented in Figures 2 through 9.

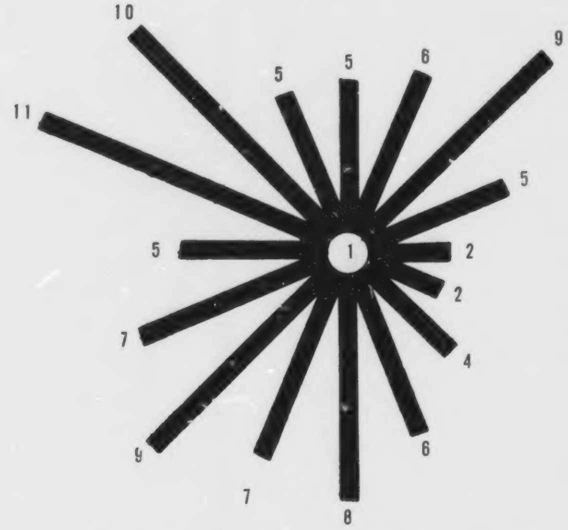

Figure 2. Annual percentage frequency of surface wind direction at LaGuardia Airport 1951 through 1960.

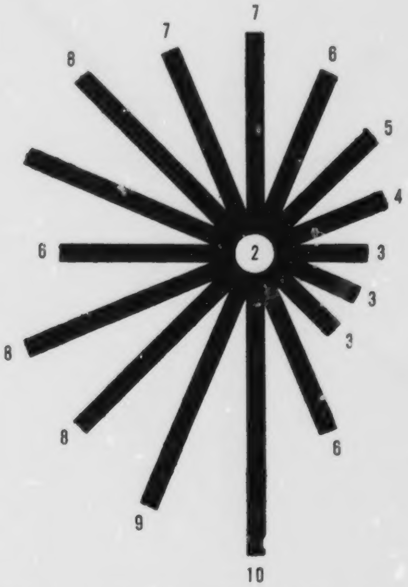

Figure 3. Annual percentage frequency of surface wind direction at J.F. Kennedy International Airport 1951 through 1960.

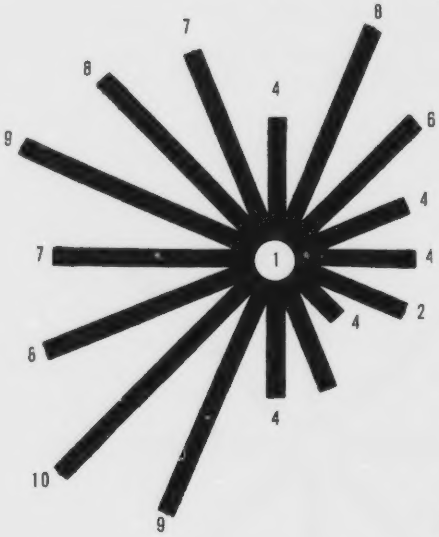

Figure 4. Annual percentage frequency of surface wind direction at Newark Airport 1951 through 1960.

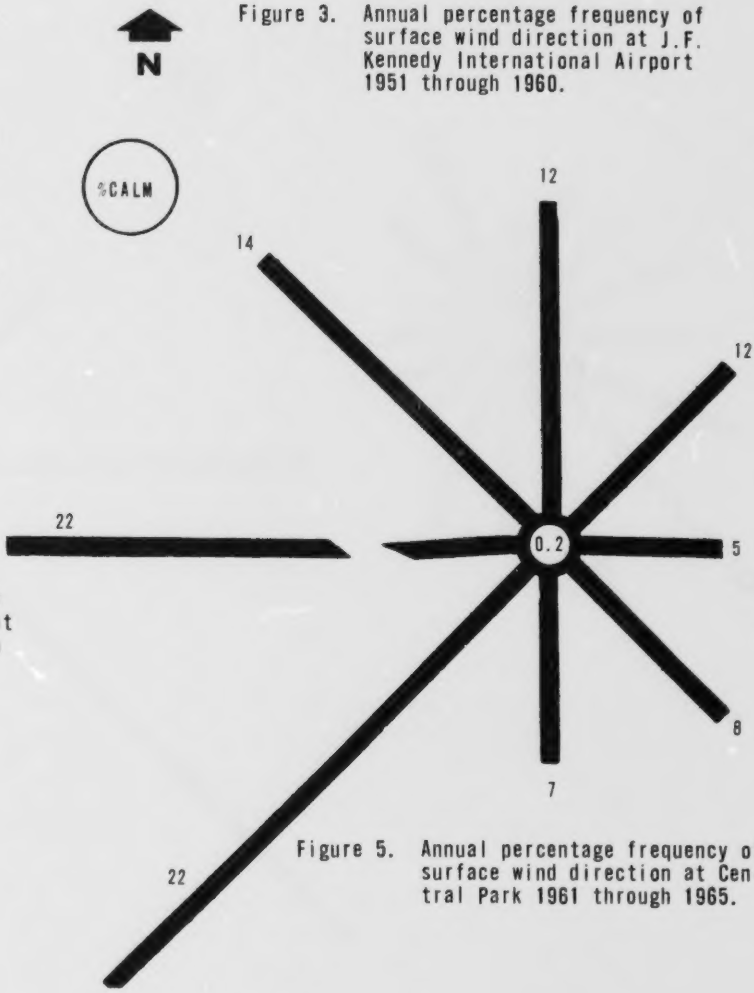

Figure 5. Annual percentage frequency of surface wind direction at Central Park 1961 through 1965.

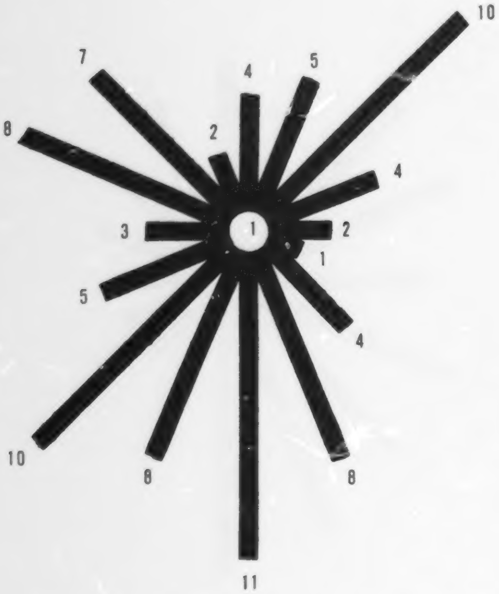

Figure 6. Summer percentage frequency of wind direction at LaGuardia Airport 1951 through 1960.

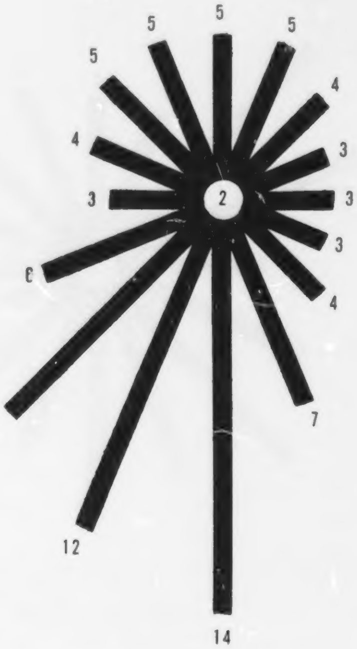

Figure 7. Summer percentage frequency of wind direction at J. F. Kennedy International Airport 1951 through 1960.

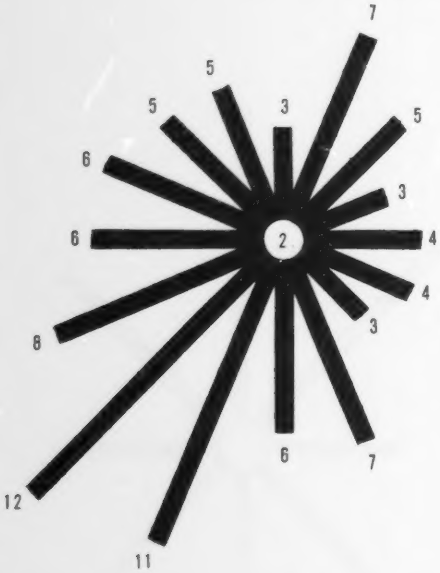

Figure 8. Summer percentage frequency of wind direction at Newark Airport 1951 through 1960.

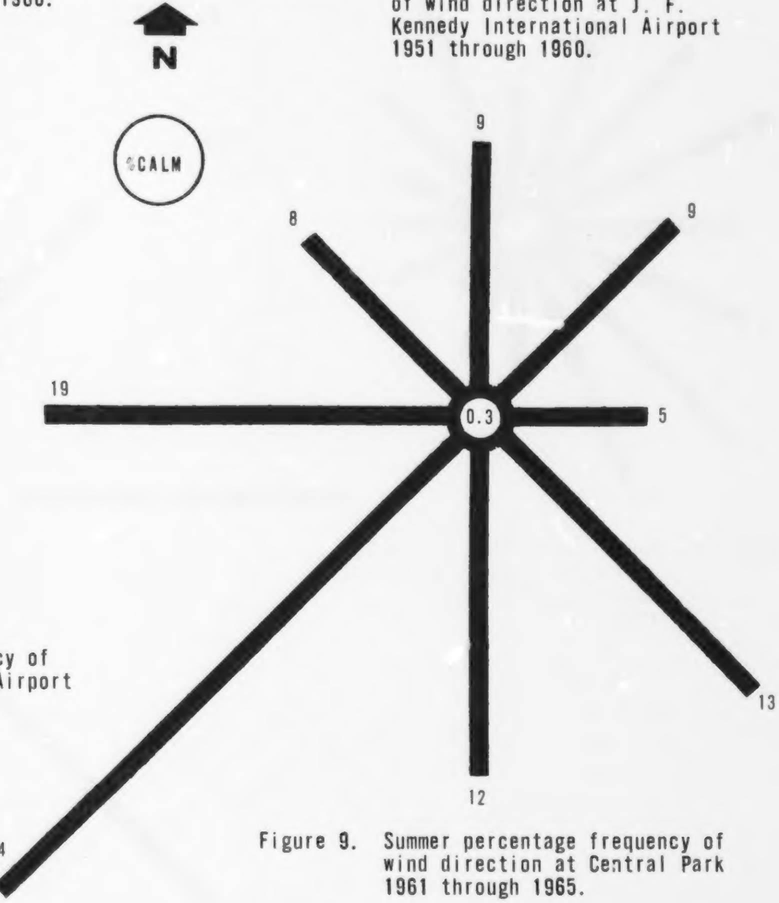

Figure 9. Summer percentage frequency of wind direction at Central Park 1961 through 1965.

There is some seasonal variation in frequency of wind directions. The modal direction is in the west to northwest sector at all stations in the winter. In summer, the mode is southwest at Newark, but more southerly at the New York stations. The New York airports are nearer the ocean and the sea breeze, a warm weather phenomenon, skews the wind direction distributions to the south (Table IV).

TABLE IV. MOST FREQUENT SURFACE WIND DIRECTIONS
CENTER OF 67-1/2-DEGREE SECTOR[a]

	Summer June - Aug.	Winter Dec. - Feb.	Annual
LaGuardia Airport	S	WNW	WNW
J.F. Kennedy Int'l. Airport	SSW	WNW	SSW
Newark Airport	SW	NW	SW

[a] References 2, 3, and 4.

When winds are light (7 mph or less) the surface wind tends to be from the southwesterly quadrant. This tendency is most pronounced at Newark.

Industrial and power plants emit effluents at some height above ground. Some stack effluents have considerable upward velocity from forced draft and from the buoyancy imparted to the plume by the high temperature of the stack gases. Wind roses for the 300-meter level (roughly 1,000 feet) provide data on the directions the effluents affected by 300-meter winds will travel. Figures 10 and 11 are annual and summer wind roses developed from the winds observed at 300

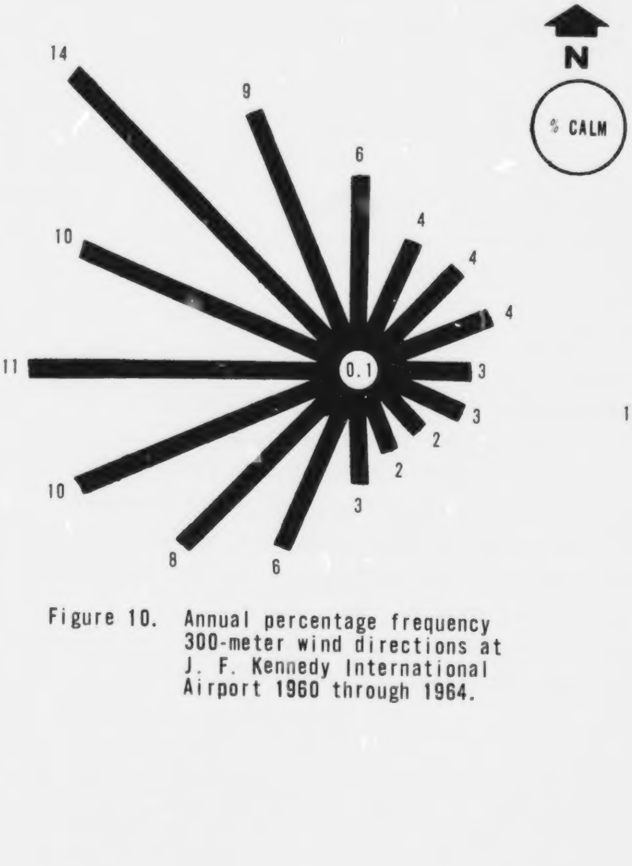

Figure 10. Annual percentage frequency 300-meter wind directions at J. F. Kennedy International Airport 1960 through 1964.

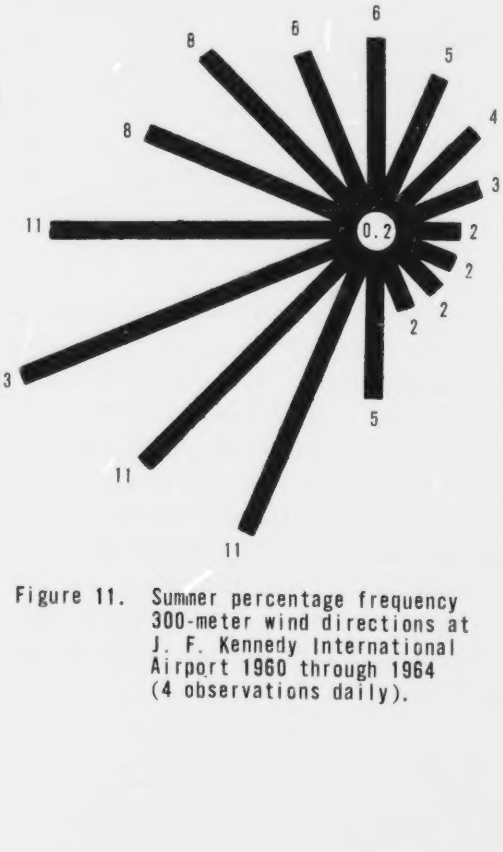

Figure 11. Summer percentage frequency 300-meter wind directions at J. F. Kennedy International Airport 1960 through 1964 (4 observations daily).

meters at J.F. Kennedy International Airport. The predominance of winds with strong westerly components is illustrated in Table V.

TABLE V

MODAL DIRECTIONS (67-1/2-DEGREE SECTOR) OF 300-METER WINDS AT J.F. KENNEDY INTERNATIONAL AIRPORT
1960 THROUGH 1964

	Spring (M-A-M)	Summer (J-J-A)	Fall (S-O-N)	Winter (D-J-F)	Annual
Modal direction	NW	WSW	WNW	WNW	WNW
Percent frequency	34	35	32	45	34

The rate at which pollutants disperse increases with increasing turbulence. As air flows over a city, vertical surfaces of tall buildings undoubtedly increase the roughness of the natural terrain intensifying the turbulence. Other than this, the factor that most markedly affects the degree of turbulence is the vertical stability of the atmosphere. When temperature inversions occur, the air is stable; vertical mixing is limited and, consequently, diffusion of pollutants is poor or severely restricted. The frequency of occurrence of inversions at J.F. Kennedy International Airport is shown in Table VI.

TABLE VI

PERCENTAGE FREQUENCY OF INVERSIONS WITH BASE WITHIN INDICATED ALTITUDE RANGE, J.F. KENNEDY INTERNATIONAL AIRPORT (not corrected for time of observation)
3,654 RADIOSONDE OBSERVATIONS, 1960 THROUGH 1964

	Winter	Spring	Summer	Fall	Annual
Ground-based	20	21	16	30	22
6-150m (20-494 ft)	1	6	7	1	4
151-500m (495-1642 ft)	16	19	18	11	16
501-1000m (1643-3282 ft)	23	10	6	13	13
Total 0-1000m(Sfc-3282 ft)	60	56	47	55	55

These data compare quite favorably with results of Hosler's study of the frequency of occurrence of inversions below 500 feet for the contiguous United States.[6/] Temperature soundings are taken at approximately 7:00 a.m. and 7:00 p.m. local standard time (EST) at the J.F. Kennedy International Airport. These times coincide roughly with times of sunrise and sunset, which are periods when inversions are much more frequent than during the middle of the day. An estimate, of the portion of the total time that inversions prevail at New York City, therefore, is too high when it is based on the Kennedy Airport. Weather stations in zones west of the Eastern Time Zone progressively make temperature soundings an hour earlier, local standard time, until in the Pacific Time Zone the observations are made at 4:00 a.m. and 4:00 p.m., local standard time. Obviously, stations to the west of New York, particularly stations in Mountain and Pacific Time Zones, collect inversion data at times more typical of day and night situations than do stations in the Eastern Time Zone.

Without correcting for overestimates of low-level inversion frequencies in New York, it is found that the New York City area annually experiences fewer inversions below 500 feet than any other portion of the contiguous United States except extreme southern Florida.[6/] Table VII presents the frequency of occurrence of inversions at several major cities in the United States.

TABLE VII

PERCENT FREQUENCY OF OCCURRENCE OF INVERSIONS
500 FEET OR BELOW FOR SELECTED CITIES
(corrected for time of observation)[a]

	Winter			
Atlanta, Ga.	36	31	29	38
Denver, Colo.	48	30	35	43
Fort Worth, Texas	34	23	22	37
Joliet, Ill. (near Chicago)	33	29	34	38
Las Vegas, Nev.	54	39	37	50
Los Angeles, Calif.	56	30	19	44
Miami, Florida	24	15	13	22
Mt. Clemons, Mich. (Detroit)	29	30	27	34
New York, N.Y.	14	16	19	26
Phoenix, Ariz.	56	39	36	51
Washington, D.C.	28	23	24	32

[a] Reference 12.

Davidson used tower measurements at Brookhaven National Laboratory, Upton, Long Island and at Indian Point Park near Peekskill, New York, to estimate the frequency of inversions in rural areas nearby to New York City.[7/] Although the terrain is different (flat at Brookhaven and a broad valley at Indian Point), he concluded that the frequency of ground based inversions at both places was about 32 percent. This frequency is considerably greater than that at J.F. Kennedy International Airport. The difference in frequency, Davidson points out, is attributed to the "heat island" effects of the city. He adds, however, because of the heat island effect, there is a tendency to find more inversions whose base is 50 to 150 or 200 m above the city, than would be found over rural areas.[8/] Temperature sounding data taken by helicopter near sunrise on June 16, 1966, illustrate Davidson's comment, (Figure 12). Westchester Airport in a suburban, if not rural, location shows a marked inversion very near ground level. A sounding taken 40 minutes later at Hudson County Park on Newark Bay shows absence of the ground-based inversion but a marked inversion at 135 meters.

The consequences of the relatively low frequency of ground-based inversions and the somewhat increased occurrence of inversions aloft over a city are considerable. Effluents emitted near the ground, when an inversion exists aloft, tend to diffuse and mix between the ground and the base of the inversion. Concentrations measured downwind will be lower than if the effluents had been emitted into a ground-based inversion. If the effluents are emitted above an inversion, whether the inversion is aloft or ground-based, little of the effluent will reach the ground. If an inversion exists aloft, however, and an elevated source emits effluents below it, significant ground-level concentrations eventually will appear downwind.

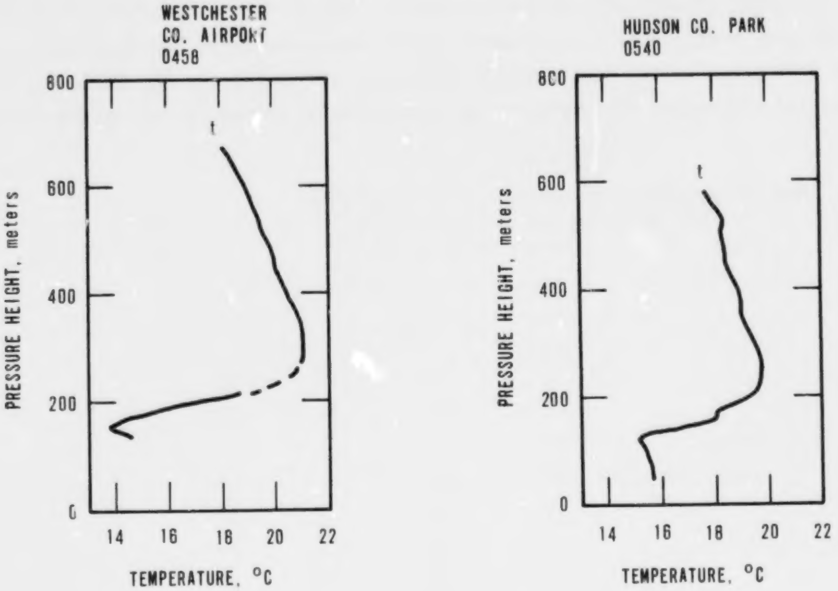

Figure 12. Temperature vs pressure height at Westchester Co. Airport, N. Y., and Hudson Co. Park, Bayonne, N. J., June 16, 1966.

Rain and snow remove air pollutants, particularly the larger particles, by washout or scavenging. Precipitation, or the lack of it, is a less important factor, however, than wind and stability in reducing air pollutant concentrations. Precipitation occurs during unstable weather regimes when diffusion conditions normally are good. Nevertheless, the frequency of measurable precipitation indicates the frequency with which some pollutants will be cleansed from the atmosphere. Compared to most of the United States, New York City is rainy. Its normal annual precipitation is 43.36 inches, distributed rather uniformly throughout the year. August is the wettest month (normal: 4.40 in.) and October the driest (normal: 3.03 in.). Measurable precipitation, 0.01 inch or more, occurs on the average of 122 days per year. It is most frequent in late winter. Both January and March average 12 days with precipitation. September and October have the fewest rainy days; normally each has eight.[1] The normal annual daily probability of rainfall is 33 percent. This is an average value for most of northeastern United States and Florida and is exceeded only in the western portion of Washington and in a narrow strip along the western slopes of the Appalachians and the eastern shores of the Great Lakes.[9]

Poor or inadequate diffusion conditions that prevail for short periods are common to most urban areas. Such conditions typically cause pollution problems, some of them severe. But the truly dramatic, and by far the most insidious, urban air pollution problems result from prolonged stagnant weather regimes. Large scale atmospheric stagnations were responsible for the notorious and disastrous Meuse Valley, Donora, and London pollution episodes. New York itself is familiar with such episodes, an especially severe one occurred in 1962.[10]

Stagnation periods in New York generally are associated with slow-moving quasi-stationary high pressure systems. Subsiding air aloft establishes an inversion at low levels and places an effective lid on vertical mixing during both day and night. Light, variable winds neither move the pollutants rapidly nor stir them thoroughly. The result is a greatly reduced volume of air to dilute the effluents, an ineffective mixing process, and a carry-over of appreciable concentrations of pollutants from one day to the next. As the stagnation persists and days of poor diffusion characteristics follow one after another, high concentrations of pollutants develop and are maintained. The frequency of occurrence of such stagnations and estimates of maximum duration are important considerations in assessing the pollution climatology of an area.

Korshover studied the frequency of anticyclonic stagnations over the area east of the Rocky Mountains. 11/ He found that the New York Metropolitan Area experienced 22 stagnation periods, each of 4 days or more, during the period 1936-1960. Donley made an extensive study of stagnation episodes in Central New Jersey; he was concerned with the area between an east-west line through Camden and another east-west line through southern Bergen County. 12/ Because the area he studied includes a substantial portion of the area of concern in this report, Donley's data are used in the following discussion. His results are comparable to Korshover's.

Donley defined a stagnation episode as a period during which his area of study was influenced by anticyclonic circulation and was located within the first two closed isobars of a high-pressure system. To be classified as a stagnation episode, the conditions had to persist for 3 days, or on four consecutive maps of the Northern Hemisphere Daily Map series. By these criteria, all stagnation periods were at least 4 days in length. He used an additional criterion: the passage of a frontal system, regardless of its intensity, terminated a stagnation period. He investigated the years 1899-1962, inclusive, and found 119 stagnation periods during these 64 years -- about two per year. One year in four had three or more stagnation periods (Table VIII), and in one year (1946) there were eight.

TABLE VIII

NUMBER OF YEARS WITH INDICATED NUMBER OF OCCURRENCES
OF STAGNATION EPISODES, 1899 THROUGH 1962
(after Donley)[a]

Number of occurrences	0	1	2	3	4	5	8
Number of years	9	22	18	5	7	2	1

[a] Reference 12.

Compared to other portions of the United States east of the Rocky Mountains, the area experienced stagnations more frequently than most of the upper Mississippi Valley, Texas, and the Plains; about as frequently as the Great Lakes area, including Detroit and Chicago; and less frequently than the Ohio Valley and the Southeastern states. In fact, from Korshover's analyses, stagnations occur in Atlanta, for example, three times as often as they do in the New York area. 11/

During the period 1899-1962, 60 percent of the stagnation periods occurred during September and October (Table IX). Furthermore, the length of the periods increased toward mid-September; nearly one-fourth of the stagnations occurring in September and October lasted 6 days or more.

Air temperature exerts an indirect influence on air pollution climatology. The amount of fuel needed for space and residential heating is related inversely to the average daily temperature. A temperature statistic, the degree-day, was developed for estimating such fuel consumption. The degree-day is commonly defined as the departure of the mean daily temperature from some standard average-daily temperature (usually 65°F). When a degree-day is used to provide estimates of heating requirements, all periods with an average daily temperature equalling or exceeding the standard are assigned zero degree-days.

TABLE IX. NUMBER OF STAGNATING ANTICYCLONES
LASTING AT LEAST THE INDICATED NUMBER
OF DAYS IN CENTRAL NEW JERSEY
1899 THROUGH 1962, (after Donley)[a]

Month	Number of Days 4	5	6	7	8	9	10
January	1						
February	2	1					
March	0						
April	6						
May	7	3					
June	6	3					
July	1						
August	5	4					
September	32	14	6	4	2		
October	37	18	10	5	1	1	
November	12	3	2	2	1	1	1
December	10	3	2	1			
Total	119	49	20	12	4	2	1

[a] Reference 12.

Based on the normal degree-days at Central Park and at LaGuardia and Newark Airports, the New York-New Jersey metropolitan area accumulates around 5,100 degree-days annually. About 238 days per year experience average daily temperatures below 65°F and presumably require some space heating.[13/] The average heating day, computed by dividing the annual total of degree-days by the number of days with an average temperature below 65°F, is 21 degree-days. A minimum-heating day is considered a day whose mean daily temperature equals or exceeds the standard 65°F and which accumulates no degree-days. A maximum-heating day was arbitrarily assigned the average number of degree-days that were experienced on the four coldest days of each year for the 5-year period 1960-64. On this basis, a maximum-heating day in New York has 48 degree-days.

Based on the assumption that SO_2 emissions from space heating sources are related to the degree-days accumulation, more SO_2 from residential sources is emitted during January than any other month. A minimum of SO_2 is emitted from such sources between late May through September. Nevertheless, some SO_2 is emitted during each month. It is estimated that 25 percent of the SO_2 in New York and 15 percent of the SO_2 in New Jersey assigned to residential sources result from the heating of water. Obviously, water for domestic purposes is heated in summer as well as in winter.

In general, the greater the number of degree-days, the greater the amount of fuel consumed for space heating. As more fuel is used, more effluents are emitted. Broadly, the source emissions from space heating are greatest on coldest days. But the coldest days in New York tend to be windy, with conditions more favorable than normal for dispersion of pollutants. Consequently, though the colder days may have the greater emission rates, the concentrations of pollutants are unlikely to be proportionally greater.

Table X gives the monthly distribution of degree days for the New York area Weather Bureau station.

TABLE X

NORMAL DISTRIBUTION OF TOTAL DEGREE-DAYS, BASE 65°F

	LaGuardia Field	Central Park	Newark Airport
July	0	0	0
August	0	0	0
September	28	31	47
October	250	250	301
November	546	552	603
December	908	902	961
January	992	1001	1039
February	907	910	932
March	760	747	760
April	447	435	450
May	141	130	148
June	10	7	11
TOTAL	4989	4965	5252

The New York-New Jersey metropolitan area normally is well-ventilated. Average wind speeds are high and occurrences of calms and inversions is low compared to occurrences in most areas of the United States. Wind directions, particularly a short distance above the surface most frequently have westerly and northerly components that tend to carry pollutants toward the sea a significant portion of the time. Short periods, measured in terms of hours, of poor conditions for effective diffusion are common, but on the average the climate of the area compared to that of most of the United States provides excellent conditions for the dispersion of atmospheric pollutants.

The New York area is, however, subject to periods of several continuous days during which extremely poor diffusion conditions persist. Serious levels of contamination not only occur, but must be expected to occur during these periods unless emissions are reduced. Based on past records, the New York Metropolitan Area will average two such episodes per year. Chances are 50-50 that an episode will occur in September or October and one-third of the episodes will persist 6 days or more. The longer episodes are most likely to occur in the fall. The longest stagnation period on record lasted 10 days; it occurred in November 1962.

SECTION III—SUMMARY OF PAST STUDIES

This report is concerned primarily with the specific operations conducted as part of the air pollution abatement action initiated under the Clean Air Act of 1965. It is appropriate, however, to consider some of the past studies that have been conducted. There have been so many of these over nearly a century that it would be impractical to cite each of them. A selection has therefore been made on the basis of applicability to this evaluation and analysis.

For ease of review, the pertinent features of the selected studies are summarized in modified tabular form in Table XI. Individual items are listed chronologically by date of publication.

TABLE XI. SUMMARY OF PAST STUDIES

Reference Number	Date	Agency or Author	Major Subject	Major Findings or Use
14	December 1956	New York University	Review of problems in New York State	Determination that much further investigation was required.
15	July 1957	Interstate Sanitation Commission	Historical review	Excellent summary of past studies and activities in the New York - New Jersey metropolitan areas.
16	January 1958	U.S. Public Health Service	Air tracer studies	Bilateral interstate transport clearly demonstrated.
17	February 1958	Interstate Sanitation Commission	Review of problems in New York - New Jersey metropolitan area.	Points out bi-lateral interstate nature of air pollution, adverse effect on public health and welfare, and property damage.
18	March 1962	Rutgers University	SO_2 damage to vegetation	Extensive SO_2 damage to spinach and fall truck crops.
19	June 1965	Rutgers University	Study of SO_2 levels in New Jersey	SO_2 highest during cold months; no change in levels over period 1957 - 1962.
20	June 1965	New York City Council	Complete review of problems in New York City	One of first official documents analyzing New York City air quality data, including an emissions inventory.
21	November 1965	Rutgers University	Evaluation of SO_2 concentrations in New Jersey	High statistical correlation between SO_2 and heating degree-days; high correlation between SO_2 and reduced visibility.
22	December 1965	New York City Council	Program and recommendations for abatement in New York City	Sulfur content of fuels must be drastically reduced.
23	(early) 1966	Rutgers University	Relationship between wind and SO_2 levels at Carlstadt, New Jersey	SO_2 concentrations and vegetation damage significantly higher when wind blowing from the east.
24	June 1966	City of New York, Mayor's Task Force	Overall review of problem in New York City	Significant percentage of air pollution originating in New York is deposited elsewhere.
25	June 1966	U.S. Public Health Service (unpublished)	Air Pollution survey of Staten Island and adjacent New Jersey conducted in summer of 1965	Data on air pollution used for comparison in Section V of this report.
26	July 1966	New Jersey State Air Pollution Control Commission	Review of air pollution control studies and efforts in New Jersey	Little information is available regarding air pollution levels or emissions in New Jersey.
27	October 1966	New York City Department of Air Pollution Control	Analysis of SO_2 levels in New York City	Levels far exceed proposed New York State ambient air quality objectives for New York City.
28	October 1966	U.S. Public Health Service	SO_2 emissions from Con-Ed plants	Use in emissions inventory of this report.

SECTION IV—PROJECT DESIGN

Pursuant to the objectives and scope of the New York - New Jersey Air Pollution Abatement Activity, the participants in the Consultation of February 17, 1966, decided that:

1. An air quality monitoring network should be established that would:
   a. Be consistent with existing or planned air monitoring sites.
   b. Be designed to sense the impact on receptor areas of primary area and point sources.
   c. Be consistent in orientation with the wind directions usually encountered during the summer season.

   The resultant monitoring network is shown in Figure 13 and described in detail in Appendix B.

2. An emissions inventory should be conducted that would locate and quantify SO_x and CO emissions from industrial, governmental, commercial, and domestic sources for the following applications:
   a. To provide positive evidence of the existence of source emissions within the study area and to define their locations, magnitudes, and relative contributions of pollutants.
   b. To provide data for calculations that would demonstrate interstate transportation of pollutants and the magnitude of impact of these emissions at selected receptor sites.
   c. To provide information on present fuel use distributional patterns and industrial emissions.

   The technique utilized is a modified rapid survey method[29] that results in a zone-oriented data presentation with emissions reported for minimum, average, and maximum degree-days. A more detailed description of the procedure is included in Appendix C.

3. A system for collecting meteorological data should be established that would:
   a. Be consistent with existing observation stations.
   b. Provide surface wind and other routine observations necessary for proper interpretation of the air quality monitoring data.
   c. Determine the "representativeness" of the 1966 sampling period, relative to past years.

   This system is shown in Figure 13 and is described in detail in Appendix B.

4. A data processing and analysis system should be established that would:
   a. Coordinate the acquisition of all types of data generated or collected during this activity.
   b. Summarize and analyze these data in standard format and by routine techniques. (The Public Health Service agreed to provide uniform tabulations to all participating agencies.)

   This system and the techniques utilized are described in detail in Appendix B.

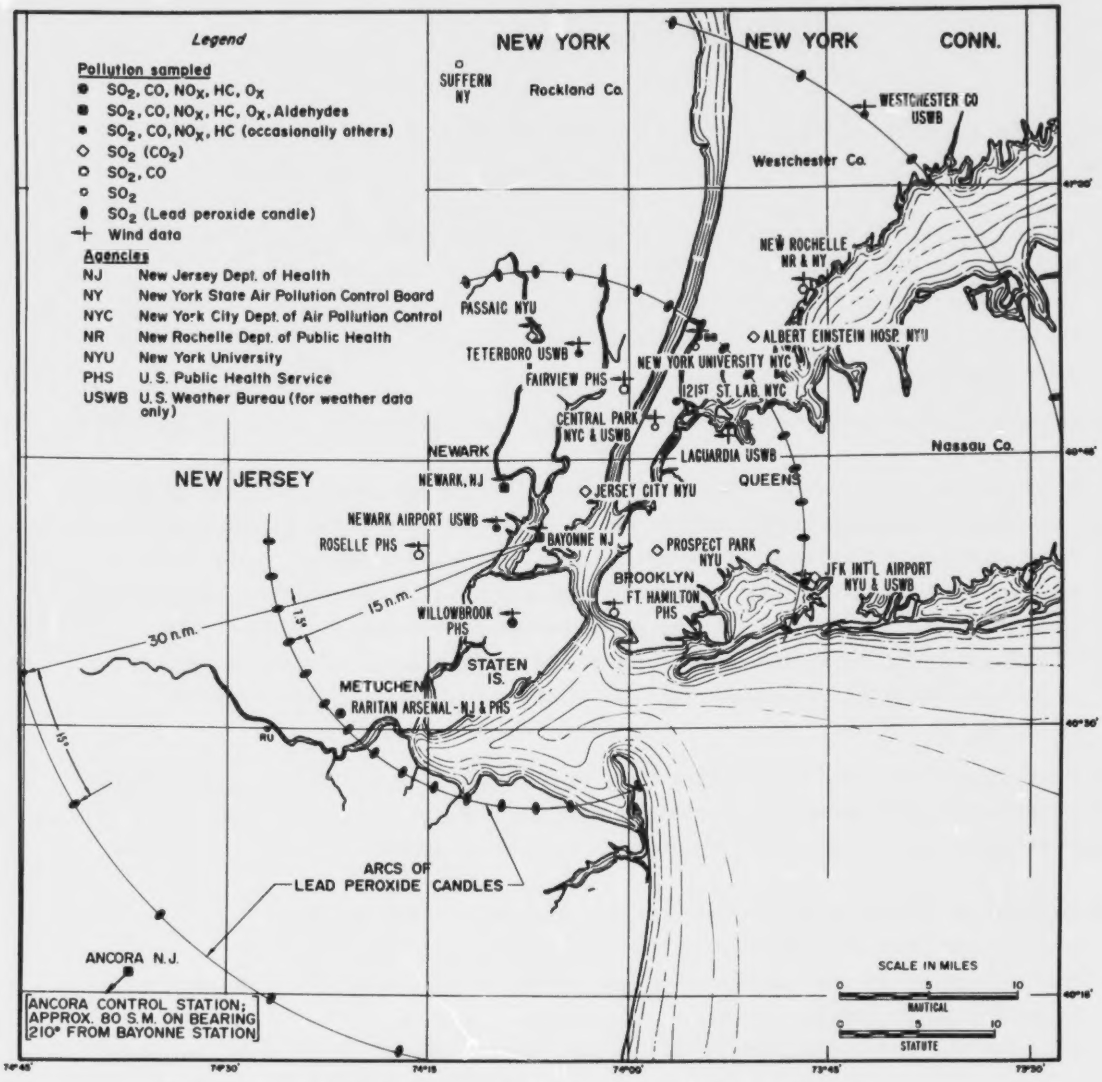
Legend
Pollution sampled
● SO_2, CO, NO_X, HC, O_X
■ SO_2, CO, NO_X, HC, O_X, Aldehydes
• SO_2, CO, NO_X, HC (occasionally others)
◇ SO_2 (CO_2)
○ SO_2, CO
○ SO_2
⬮ SO_2 (Lead peroxide candle)
-+ Wind data
Agencies
NJ New Jersey Dept. of Health
NY New York State Air Pollution Control Board
NYC New York City Dept. of Air Pollution Control
NR New Rochelle Dept. of Public Health
NYU New York University
PHS U.S. Public Health Service
USWB U.S. Weather Bureau (for weather data only)
NEW YORK
NEW YORK
CONN.
SUFFERN NY
Rockland Co.
WESTCHESTER CO USWB
Westchester Co.
NEW ROCHELLE NR & NY
PASSAIC NYU
TETERBORO USWB
ALBERT EINSTEIN HOSP. NYU
NEW YORK UNIVERSITY NYC
FAIRVIEW PHS
121ST ST. LAB. NYC
CENTRAL PARK NYC & USWB
LAGUARDIA USWB
Nassau Co.
NEWARK
NEW JERSEY
NEWARK, NJ
JERSEY CITY NYU
QUEENS
NEWARK AIRPORT USWB
BAYONNE NJ
ROSELLE PHS
PROSPECT PARK NYU
BROOKLYN
JFK INT'L AIRPORT NYU & USWB
15 n.m.
15°
30 n.m.
WILLOWBROOK PHS
FT. HAMILTON PHS
STATEN IS.
METUCHEN
RARITAN ARSENAL-NJ & PHS
RU
15°
ARCS OF LEAD PEROXIDE CANDLES
ANCORA N.J.
ANCORA CONTROL STATION; APPROX. 80 S.M. ON BEARING 210° FROM BAYONNE STATION
SCALE IN MILES
0 5 10
NAUTICAL
0 5 10
STATUTE
41°00'
40°45'
40°30'
40°15'
74°45'
74°30'
74°15'
74°00'
73°45'
73°30'

Figure 13. New York-New Jersey Air Quality Monitoring Network

SECTION V—RESULTS OF COMPREHENSIVE SURVEY

AIR QUALITY DATA

Sulfur Dioxide

Sulfur dioxide concentrations were measured continuously at 15 of the 89 sampling locations in the study area for periods of 3 to 6 months in 1966. Both the conductivity and colorimetric techniques were used; however, the majority of the data were generated by the conductivity method. Even though some stations were in operation as early as January 1966, the bulk of the data are from the months of June, July, and August, 1966. For this reason, primary discussion of results will be restricted to summer 1966 data.

Frequency distributions of the hourly SO_2 concentrations were computed for the summer at all stations. A summary of these data appears in Table XII.

TABLE XII
FREQUENCY DISTRIBUTIONS OF HOURLY AVERAGES OF
SULFUR DIOXIDE CONCENTRATIONS (ppm) - JUNE THROUGH AUGUST 1966

Station	Min.	Percent of Time Listed Concentration is Exceeded					Max.	No. of Hourly Observations	Location
		90%	70%	50%	30%	10%			
001	0.01	0.01	0.03	0.05	0.09	0.21	0.37	1710	Willowbrook
002	0.01	0.01	0.02	0.03	0.05	0.09	0.34	1203	Roselle
003	0.01	0.01	0.03	0.05	0.08	0.15	0.38	1106	Fairview
005	0.03	0.06	0.08	0.10	0.12	0.16	0.30	1293	Raritan
006	0.03	0.04	0.07	0.09	0.12	0.18	0.65	1964	Bayonne
007	0.03	0.04	0.06	0.08	0.10	0.14	0.90	1956	Newark
008	<0.01	0.02	0.04	0.08	0.14	0.31	0.50	1038	Einstein
009	<0.01	0.02	0.03	0.05	0.08	0.15	0.30	763	Prospect
010	<0.01	0.02	0.04	0.06	0.08	0.15	0.48	1356	Jersey City
011	<0.01	0.02	0.03	0.05	0.08	0.15	0.40	1769	JFK
012	0.02	0.04	0.06	0.08	0.10	0.16	0.30	1272	NYU
013	0.01	0.01	0.03	0.05	0.09	0.19	0.64	1543	Central Park
014	<0.01	0.02	0.05	0.08	0.12	0.24	0.93	2197	121st Street
016	<0.01	0.01	0.02	0.03	0.05	0.10	0.23	754	New Rochelle
029	<0.01	0.03	0.05	0.07	0.10	0.18	0.35	1338	Passaic

Thirteen of the 15 stations, the exceptions being New Rochelle (#16) and Roselle (#2), showed hourly concentrations in excess of 0.10 ppm at least 20 percent of the time. Some were considerably higher; for example, at both Bayonne (#6) and the Bronx (#8) stations 41 percent of all readings were greater than 0.10 ppm. Of the more than 21,000 hourly readings obtained during the survey, about 30 percent exceeded 0.10 ppm. Similarly, high concentrations were noted in the distribution of the daily averages, which at five stations exceeded 0.10 ppm on more than one-third of the days (Table XIII).

TABLE XIII
SUMMARY OF DAILY (24 hour) AVERAGES OF SULFUR DIOXIDE CONCENTRATIONS - JUNE THROUGH AUGUST, 1966

Station	Min. Daily Avg, ppm	% of Days 0.10-ppm Daily Average Was Exceeded	Max. Daily Avg, ppm	No. of Days of Observation	Location
001	0.01	15	0.19	79	Willowbrook
002	0.01	3	0.12	47	Roselle
003	0.01	18	0.16	43	Fairview
005	0.04	52	0.16	51	Raritan
006	0.05	42	0.16	75	Bayonne
007	0.05	25	0.20	89	Newark
008	0.02	42	0.24	44	Einstein
009	0.01	12	0.12	32	Prospect
010	0.03	15	0.20	57	Jersey City
011	0.02	24	0.19	73	JFK
012	0.03	24	0.16	53	NYU
013	0.01	43	0.23	71	Central Park
014	0.01	38	0.35	92	121st Street
016	0.02	6	0.31	33	New Rochelle
029	0.02	31	0.21	56	Passaic
All Stations	0.01	27	0.35	895	

Since the bulk of this current air quality sampling was performed during the summer, it is desirable to estimate the concentration levels that would be expected during the winter season. Sampling has been performed during all seasons at the New York City Department of Air Pollution Control Laboratory, 170 East 121st Street, Manhattan, since 1957. These data were evaluated, and frequency distributions of daily values were computed for each month. Distributions for summer and winter months are shown graphically in Figure 14. The analysis revealed that SO_2 concentrations during the winter months, i.e., December, January, and February, consistently were 2 to 2-1/2 times greater than the corresponding summer levels found in June, July, and August. Sampling (1964-1966, intermittent) by the Interstate Sanitation Commission on Staten Island during both winter and summer months has shown a ratio of about 2.5:1 between winter and summer levels. This same seasonal variation in average levels is demonstrated by results from the U.S. Public Health Service Continuous Air Monitoring Program, which includes data from six major urban areas.

Based on this evidence, frequency distribution plots of expected 1966-67 winter levels were extrapolated from the actual 1966 summer data for three selected stations. These distributions of daily average concentrations are shown in Figure 15. It should be noted that the stations selected for analysis include one station located in the midst of numerous point sources of

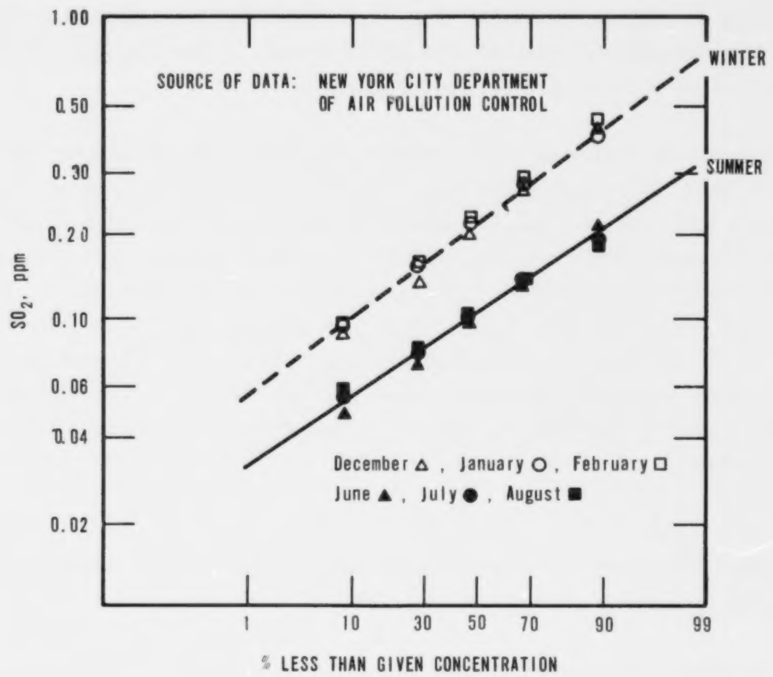

Figure 14. Frequency distribution of daily SO_2 values by summer and winter months from 1957 to 1966.

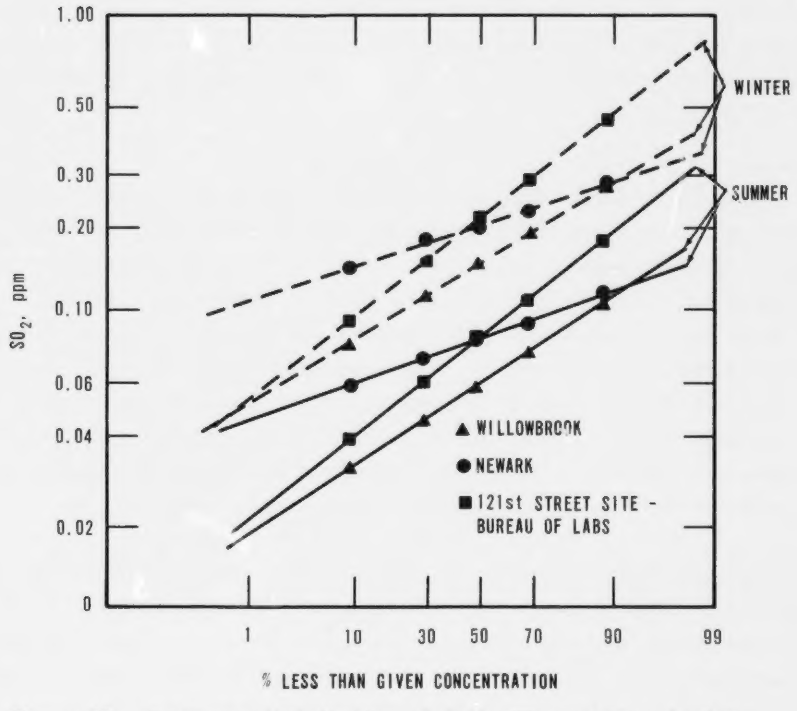

Figure 15. Frequency distribution of daily SO_2 averages showing summer 1966 values and projected winter levels.

emissions (121st St.); one located in the middle of a large high-density emission zone (Newark); and the third located in a low-density emission zone (Willowbrook). These stations are representative of the various types of site locations utilized in the network.

Examination of these curves indicates that in winter, SO_2 levels for 24-hour periods probably will exceed 0.10 ppm at least 80 percent of the time at multiple locations throughout the bistate area. This extrapolation indicates that the SO_2 problem is one of continuous high levels of overall concentrations throughout the "core area" rather than either frequent incidents of short-term peak concentrations superimposed on relatively low background concentrations or a few localized "high-level" receptor areas coupled with many areas recording significantly lower average values. This conclusion is given further support if we compare the percent of time that the hourly average concentrations at all sampling sites exceeded 0.25 ppm with the percent of time the daily average exceeded 0.10 ppm. The 24-hour average exceeds 0.10 ppm 26 percent of the time, whereas the hourly average concentration exceeds 0.25 ppm about 4 percent of the time.

This analysis also is consistent with the findings relative to emission sources of SO_2, which are discussed later in this report.

For comparison purposes, Table XIV lists some SO_2 standards or criteria adopted or presently proposed for various urban areas in the United States. Examination of the data collected during the summer of 1966 reveals that SO_2 concentrations exceeded practically all of these criteria at a majority of the reporting stations. Projected winter concentrations at all stations would be expected to exceed the entire set of listed criteria on numerous occasions. A plot, Figure 16 of the projected 1966-67 values for Roselle, the station reporting the lowest summer SO_2 values in the network, indicates the minimal frequency at which excess concentrations would be expected in the network area during the winter season.

To provide an indication of sulfur dioxide concentrations at varying distances from the "core-network" stations, two concentric rings of lead peroxide "candle" samplers were established, with radii of 15 and 30 nautical miles respectively, and centered on the Bayonne site (geographical center of the study network). Although the lead candle does not measure SO_2 directly, experimentation and experience have shown that a relationship exists between the monthly average sulfation value obtained by this technique and 30-day average SO_2 levels measured by the continuous analyzers.[30/] Estimated isopleths based on sulfation values from approximately 70 stations are plotted in Figure 17 to depict the geographical distribution of SO_2 pollution during the summer of 1966 over the entire activity area. These results are in close agreement with those obtained at various automatic equipment stations where both techniques were employed simultaneously.

The observed pattern delineates two major "hot-spots" within the interstate area. One is centered about the intersection of the Boroughs of Manhattan, Bronx, and Queens, in New York. The other is found in New Jersey, extending from South Amboy to Carteret, adjacent to the Arthur Kill. As would be expected from monthly integrated samples, these two zones generally coincide with those of highest density SO_2 emissions, as determined from the inventory of sources.

TABLE XIV
SULFUR DIOXIDE AMBIENT AIR STANDARDS OR CRITERIA ADOPTED OR PROPOSED FOR AREAS IN THE USA, 1966

Area	Standard Criteria Concentration, ppm	Averaging Time, hours
Adopted		
California	0.30	8
Colorado	0.10 > 1% of time any 3 Months	24
	0.50 > 1% of time any 3 Months	1
Dade County, Fla.	0.10	8
New York State (Vary according to regions)	0.10 > 1% of time To 0.15 > 2% of time	24
	0.25 > 1% of time To 0.40 > 2% of time	1
Proposed		
St. Louis (Metropolitan)	0.02	Annual average
	0.10 > 1% days in any 3 consecutive Months	24
	0.20 > once in any 4 consecutive days	1
Pennsylvania	0.15 > once in any 100-day period 0.30 > once in any 100 consecutive hour period	24

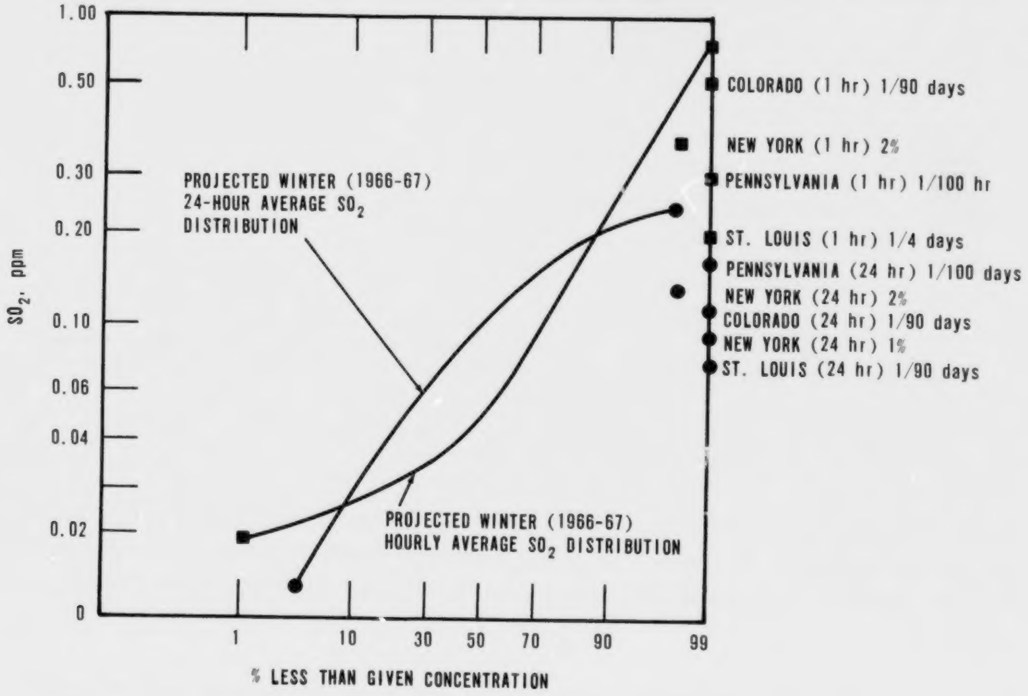

Figure 16. Comparison of Roselle SO_2 projections with various SO_2 criteria.

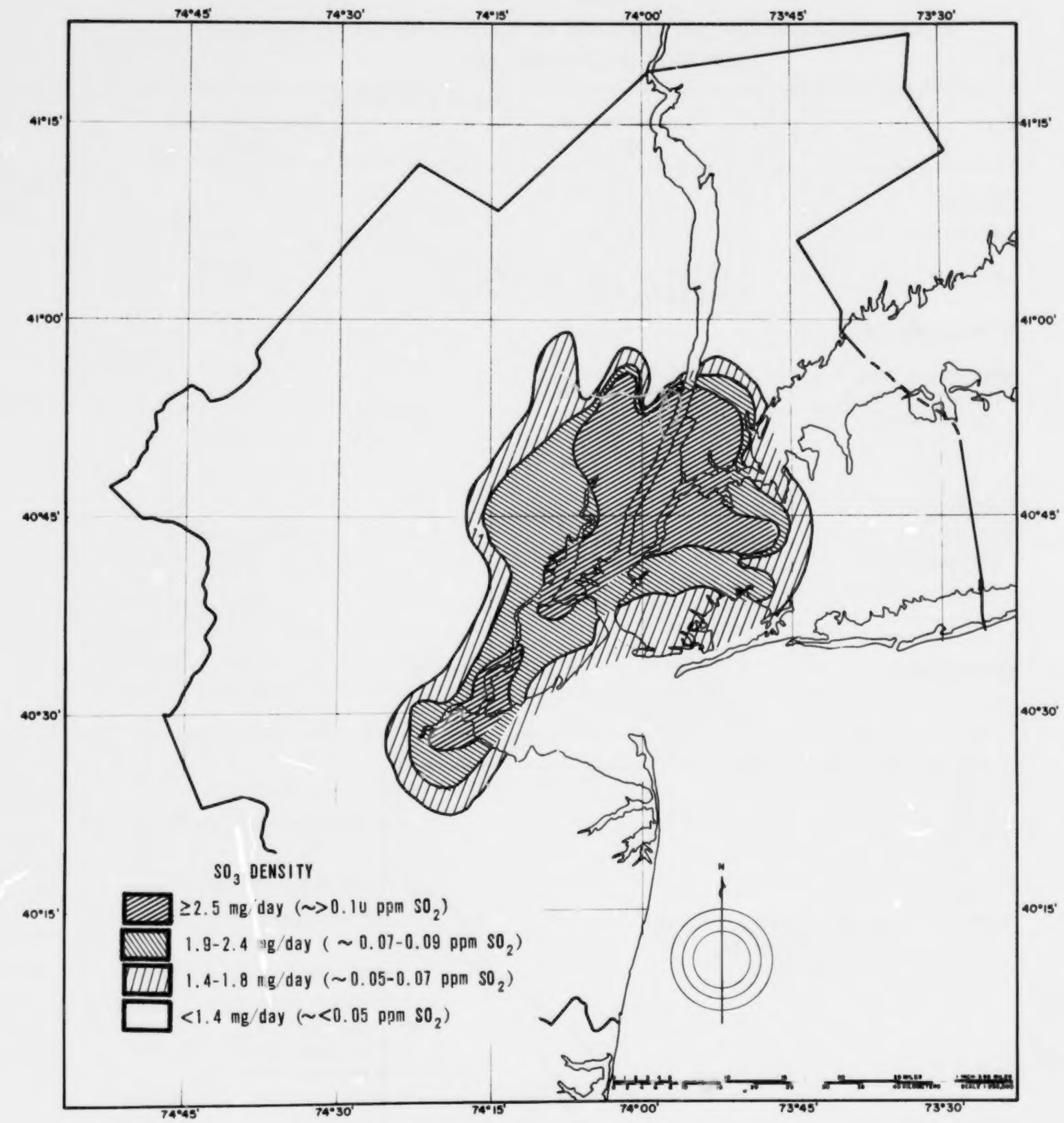
74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
41°15'
41°00'
40°45'
40°30'
40°15'
N
SO₃ DENSITY
≥2.5 mg/day (~>0.10 ppm SO₂)
1.9-2.4 mg/day (~ 0.07-0.09 ppm SO₂)
1.4-1.8 mg/day (~0.05-0.07 ppm SO₂)
<1.4 mg/day (~<0.05 ppm SO₂)

Figure 17. Geographical Distribution of sulfation rates for summer 1966.

Further, the summertime diffusion of significant SO_2 pollution (>0.05 ppm) covers approximately 20 percent of the interstate abatement area, and affects approximately two-thirds of the population. In winter, the levels of SO_2, the area of contamination, and the number of people affected all would be greater.

The effects of SO_2 on human health, on materials, and on vegetation have been documented by both field and laboratory studies. To appraise the extent and frequency of occurrence of

SO_2 pollution that would produce specific effects, data from the New York City Department of Air Pollution Control station (#14) on Manhattan were examined for the period January through August 1966. Data relative to two selected dosage criteria are summarized in Table XV.

TABLE XV
SO_2 POLLUTION EPISODES RELATED TO SELECTED DOSAGE CRITERIA
STATION #14 - JANUARY THROUGH AUGUST 1966 (243 days)

Dosage Criteria	Number of Occurrences	Percent of Occurrences	Total Dosage, ppm - hr		
			Min.	Avg	Max.
24- hr average ≥ 0.10 ppm	154[a]	63	2.4	3.84	9.84
8- hr average ≥ 0.30 ppm	94	13	2.4	3.18	5.11

[a] Number of calendar days.

Possible effects related to a total dosage accumulated over a 24-hour period at station 14 are as follows:

1. A total dosage of 6.00 ppm-hr, which is the threshold for detection of increase death rate in humans and deteriorating health of bronchitis patients,[31] occurred in 13 percent of the episodes.
2. A total dosage of 6.72 ppm-hr, which produces tissue damage in sensitive vegetation,[32] occurred in 8 percent of the episodes.
3. A total dosage of 4.80 ppm-hr, which produces a calculated reduction in visibility of 2 miles at 70 percent relative humidity,[33] occurred in 29 percent of the episodes.

Possible effects related to a total dosage accumulated over an 8-hour period at station 14 are as follows:

1. A total dosage of 4.80 ppm-hr which is the threshold for increased respiration and pulse rates of susceptible humans,[34] occurred in 7 percent of the episodes.
2. A total dosage of 4.00 ppm-hr, which produces a calculated reduction in visibility to 0.85 miles assuming a 70 percent relative humidity,[33] occurred in 13 percent of the episodes.
3. A total dosage of 3.20 ppm-hr, which produces tissue injury to sensitive vegetation,[32] occurred in 40 percent of the episodes.

To determine if ambient levels of SO_2 produced tissue damage in vegetation indigenous to the area, a series of field inspections was carried out by an experienced plant pathologist. During the early May 1966 growing season, he collected specimens of local vegetation that appeared to exhibit acute or chronic symptoms of SO_2 injury. Following laboratory assessment of the tissue cell damage, he verified the existence of typical SO_2 injury[35],[36],[37] to tulip, crocus, and wild lettuce growing at the Brooklyn Botanical Gardens, as well as similar effects on tulip, crocus, and columbine growing at several locations on Staten Island.

During the similar period of 1965, this same specialist observed and verified typical SO_2 damage to silver maple trees, begonia, geranium, and corn plants grown in Perth Amboy.

In an attempt to observe SO_2 attack on sensitive vegetation grown under controlled conditions, four specially designed exposure chambers were installed during the period July 18 through Oct. 5, 1966, in Brooklyn and on Staten Island in New York, and at Roselle and Bayonne in New Jersey. A control station, using charcoal-filtered air, was placed in operation at the Staten Island site. During the exposure period of July 18 through August 12, traces of SO_2 injury were observed on cotton and petunia plants at the Brooklyn and Roselle stations. No further "clear-cut" SO_2 damage was found until mid-September when the cotton and petunia plants at Roselle and Bayonne exhibited injury on 5 and 10 percent, respectively, of the total leaf surface

The most striking evidence of damage to sensitive species during this past summer occurred with tobacco (W_3) plants exposed at all four locations for the ten week period. These plants all exhibited acute leaf tissue damage different from that usually found when this species of tobacco is exposed to ozone.[36/] Damage was identical to that reported by Menser et al.,[37/] which they attributed to simultaneous exposure to both ozone and sulfur dioxide. Levels of coexposure needed to produce this injury are approximately 0.03 and 0.25 ppm of ozone and SO_2, respectively. Work presently being carried out by U.S. Department of Agriculture plant physiologists at the Robert A. Taft Sanitary Engineering Center of the Public Health Service, Cincinnati, Ohio, has confirmed this finding. In this case, identical injury was produced with even lower levels of SO_2 (0.10 ppm) combined with ozone (0.03 ppm).[38/] These combinations occurred frequently at all sites during the observation period.

In addition to tissue destruction, all vegetation species exposed to the ambient air suffered severe growth suppression or dwarfing. Comparable plants grown in the control station at Willowbrook (#1) had longer leaves, hardier stems, larger root systems, darker green color, and a generally more vigorous growth appearance than those grown in exposure chambers. For comparison purposes, Table XVI lists measurements made on the stems and root systems of tobacco plants exposed for 10 weeks at the four stations.

TABLE XVI

DIAMETER OF STEM AND WEIGHT OF THE ROOT SYSTEM OF TOBACCO PLANTS EXPOSED TO AMBIENT AIR-JULY 18 THROUGH OCT. 5, 1966

Station	Diameter of Stem, centimeters	Root System Weight, grams
Willowbrook Control (filter)	1.9	1,012
Bayonne	1.3	160
Roselle	1.6	299
Willowbrook	1.7	337
Brooklyn Botanical Gardens	1.7	344

Research and field studies have shown that some materials exposed to a polluted atmosphere deteriorate more rapidly than those exposed to clean air. Steel plates* were exposed to the ambient air at three locations: Perth Amboy, and Elizabeth in New Jersey and Staten Island in New York.

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*Specially prepared mild steel, used to obtain relatively short-term corrosion measurements.

Plates also were exposed at Mays Landing, New Jersey, a control site relatively free of high-density pollution concentrations. Each plate was exposed for 3 months. Following their exposure, weight loss of the plates caused by atmospheric oxidation, both natural and pollution-induced, was determined. Results are shown in Table XVII.

TABLE XVII

CORROSION OF STEEL PLATES (3 x 4 inch)
JANUARY THROUGH AUGUST 1966
(weight loss in mg/day)

Station	Jan. - Mar.	April - June	July - Aug.	Average
Mays Landing (Control)	26.6	23.8	29.7	26.7
Perth Amboy	36.9	39.0	41.2	39.0
Elizabeth	32.2	27.3	33.4	31.0
Staten Island	27.1	34.0	38.7	33.3

Both quarterly and average corrison rates at Perth Amboy were greater (45%) seasonally and annually, than at the control site. The Perth Amboy site is located in the midst of multiple point sources and area emissions of SO_2. Although other exposure sites yielded specimens with more weight loss than their corresponding control, the differences in weight loss were not nearly so great.

Sulfates and Acid Aerosol (H_2SO_4)

Daily samples (midnight to midnight) of airborne particulates were collected by means of high-volume filter samplers at nine locations during the summer. These samples were analyzed for total sulfates and their acid fraction.

Sulfates and sulfuric acid mist or aerosol are introduced into the atmosphere by many specific industrial processes (mineral processing, metal smelting, acid production, petroleum refining, etc.); however, a major source of these compounds is the photooxidation of SO_2 in the ambient atmosphere.[39/] Also, hydrogen sulfide produced industrially or by anaerobic bacterial action can be atmospherically oxidized to sulfate.[40/]

The majority of sulfate particulates are of a size that can be breathed deep into and retained in the lungs.[41/] Both the neutral sulfate and its acid fraction remain biologically active and can damage the ill-protected tissue of the lungs. Studies at Harvard University indicated that the greatest degree of resistance to breathing by laboratory animals was produced by neutral sulfate particles in the same size range as those found in urban air.

Results of the 1966 sampling are shown in Table XVIII.

In general, correlation exists between the acid fraction and the total sulfate concentration averages, a ratio of approximately 1:4. Sulfate values reflect the same distribution of pollution indicated by the lead peroxide candle sulfation rates.

TABLE XVIII

TOTAL AND ACID SULFATE CONTENT OF PARTICULATE SAMPLES TAKEN WITH HIGH-VOLUME SAMPLER JULY THROUGH AUGUST 1966

Station	Total Sulfate ($\mu gSO_4/m^3$) Min.	Avg	Max.	Acid Aerosol[a] ($\mu g\ H_2SO_4/m^3$) Min.	Avg	Max.
Willowbrook	4	22	61	<1	4	10
Roselle	4	18	40	<1	4	13
Fairview	5	22	56	1	5	11
Ft. Hamilton	5	19	52	1	4	19
Raritan	10	17	31	2	4	19
Bayonne	7	24	38	2	6	22
Newark	2	13	28	4	6	7
121st St.	10	23	66	3	4	8
New Rochelle	6	16	42	2	4	8

[a] Assumed that all acid aerosol is present as H_2SO_4.

When summer sulfate levels measured at Newark and Manhattan are compared with seasonal and annual (1961-64) data from the National Air Sampling Network[42/] for these cities, it appears that summer values are approximately two-thirds of the annual average and about one-half of the wintertime concentrations. Based on these approximations, an average annual total sulfate value of 28 $\mu g/m^3$ would be anticipated for the "core" of the interstate metropolitan area. This is more than twice the mean yearly sulfate concentration (12 $\mu g/m^3$) reported for 23 urban stations across the nation by the NASN for the years 1961-64.

Dohan[43/] studied the incidence of respiratory illnesses lasting more than 7 days in female employees in five cities. The results of this study showed excellent correlation (0.964) between the average concentration of suspended sulfate in these urban atmospheres and the rate of respiratory illnesses. The average sulfate concentrations for the five cities ranged from 5 to 20 $\mu g/m^3$.

Acid aerosols accelerate the deterioration of some materials. Nylon fabric panels 3 by 4 inches in size were exposed at three sites in the area, the same sites used for other "effects" measurements noted in this report. For the period of June through August 1966, the monthly average number of defects found in these nylon panels at the Perth Amboy station was 4, at Elizabeth the average was 9, and at Staten Island 3. Panels at the control station at Mays Landing recorded no defects for this period. It should be noted that the Elizabeth site is in relative proximity to several industrial sources of sulfuric acid mist emissions.

Hydrogen Sulfide

Hydrogen sulfide (H_2S) is a colorless gas that has an offensive odor even in very low concentrations. Hydrogen sulfide measurements were taken with impregnated tape samplers at four sites (Willowbrook, Roselle, Fairview, and Raritan)during July and August 1966. Results of this preliminary sampling indicated no chronic H_2S problem in the areas sampled, but past acute concentrations have been high enough at times to cause periodic odor complaints, and to darken house paint.

A relative measure of hydrogen sulfide also is provided by exposure of silver plates. Field studies have shown that H_2S at relatively low concentrations tarnishes silver.[44] Plates were exposed during September 1966 at 54 sites located on two circles of radii of 15 and 30 nautical miles from a point in Bayonne, New Jersey, and seven additional plates were exposed at stations located within the inner circle of this network. Results of the silver plate exposures are presented in terms of percent decrease in reflectance; this loss in reflectance is related to the amount the plate tarnishes during the month. Results of these exposures reveal that the greatest loss in reflectance generally occurred at those sites within the inner circle, whereas the least percent decrease occurred at those stations in the outer ring. These results are not surprising since the inner core area of the silver plate network is known to contain many industries whose processes result in emissions of H_2S. These results are substantiated by the exposure of silver plates at five "effects" stations from January through June 1966 at Elizabeth, Perth Amboy, and Mays Landing in New Jersey and Staten Island and Brooklyn in New York. All but one of these stations, the exception being Mays Landing, a control station near Atlantic City, recorded values consistent with those found in the inner core stations of the network (Table XIX).

TABLE XIX

SILVER TARNISHING, MONTHLY INTEGRATED SAMPLES-1966

Station	Exposure Dates	Loss in Reflectance, %
Staten Island	Jan-June	76
Brooklyn	"	75
Perth Amboy	"	68
Elizabeth	"	72
Inner Core (7 Sites)	September	66
Inner Ring (34 Sites)	"	52
Outer Ring (20 Sites)	"	40
Mays Landing (Control)	Jan-June	43

The Interstate Sanitation Commission and agencies of the City of New York and the State of New Jersey have reported periodic episodes of odor nuisance, particularly in the vicinity of Newark and northern Staten Island. In many instances, it has not been possible to identify the sources or types of odors, but hydrogen sulfide and mercaptans from industrial processes are known to contribute to these episodes. These odors are usually localized within 1 or 2 miles of the known or suspected source, but at times they have traveled from New Jersey as far as Brooklyn, Manhattan, and Nassau Counties.

The highest incidence of H_2S measured by silver plate exposures occurred in those areas reporting the majority of complaints. These measurements and the complaints lead to the conclusion that although H_2S is possibly not the only offender in these odor episodes, it is at least one of the major contributors.

Carbon Monoxide

Carbon monoxide (CO), a colorless, odorless, and poisonous gas, is produced by any process that involves the incomplete combustion of carbonous material. Despite the enormous quantities of coal, oil, gas, and organic refuse burned, emissions from motor vehicles account for approximately 96 percent of the CO emitted into the atmosphere of the 17-county area. The widespread use of motor vehicles, which discharge pollution near ground level, makes this contaminant one of the most common and homogeneously distributed hazards to the population.

Carbon monoxide measurements were obtained at nine stations throughout the "inner core" of the sampling network. These sites were selected to provide a representative sampling of ambient CO concentrations over the study area.

The distribution of hourly average CO concentrations is presented in Table XX.

TABLE XX. FREQUENCY DISTRIBUTIONS OF HOURLY AVERAGE OF
CARBON MONOXIDE CONCENTRATIONS JUNE THROUGH AUGUST, 1966 (ppm)

Station	Min.	% of Time Listed Concentration is Exceeded 90%	50%	10%	Max.	No. of Observations
Willowbrook	<1	<1	2	4	7	2053
Roselle	<1	2	6	10	16	1282
Fairview	<1	1	3	5	10	1308
Raritan	<1	<1	2	5	8	1257
Bayonne	<1	<1	2	4	9	1894
Newark	3	6	9	14	25	2158
Central Park	<1	2	5	11	20	1827
121st Street	<1	2	3	5	11	2164
New Rochelle	1	6	10	14	21	1794

The average hourly mean CO value for all stations during the summer of 1966 was approximately 5 ppm. This value agrees well with that reported for the six urban sites in the Continuous Air Monitoring Program for 1964,[45/] i.e., 6 ppm. The two stations reporting the highest concentrations during the period June through August, Newark and New Rochelle, are located in mid-town, about 100 feet from heavily trafficked intersections. These stations yielded hourly mean concentrations about 2 times the mean for all stations and about 3 times the mean of the other seven stations, which were 1/4 to 1 mile from locations with dense automotive traffic.

Tentative air quality objectives for the State of New York include the following limit: Exposure to 15 ppm CO for 8-hour intervals is to be exceeded no more than 15 percent of the time on an annual basis. Data from the nine monitoring sites were examined for the number of 8-hour intervals that a level of 15 parts CO per million parts of air was exceeded during the 1966 summer season. An average concentration of 15 ppm for intervals of 8 hours or longer was exceeded 10.6 percent of the time at the Newark station, 3.4 percent of the time at the Central Park station, and 7.6 percent of the time at the New Rochelle station. The 15 ppm level was not exceeded at any of the other stations over any 8-hour period.

In-traffic sampling was conducted recently in six cities by a mobile monitoring unit of the Public Health Service.[46/] The **short term** sampling runs were made on expressways, arterial highways, bridges, and in center-city traffic during heavy traffic hours. For comparison purposes, a summary of these data is presented in Table XXI.

TABLE XXI

AVERAGE IN-TRAFFIC[a] CO CONCENTRATIONS MEASURED IN SIX CITIES DURING 1965-66 (ppm)

City	No. of Runs	% of Time Concentration Listed Was Exceeded 90%	50%	10%	Range of Peak Averages
Atlanta	23	21	28	36	37-96
Baltimore	58	13	20	31	10-95
Chicago	42	16	25	40	20-100
Cincinnati	15	13	20	29	12-63
Louisville	38	12	19	30	10-66
New York	95	22	33	49	19-95

[a] Samples taken during heaviest traffic hours (0700-1000, 1530-1830)

The CO concentrations measured in New York traffic were the highest found in the six cities monitored. These short term samples, taken adjacent to or inside motor vehicles, yielded a median concentration 3 to 15 times greater than the medians of hourly samples at the nine fixed monitoring sites.

The State of New York tentative air quality objectives for CO state that a concentration of 30 ppm for 8 hours (240 ppm-hr) should not be exceeded at any time. In many localized segments of the bistate area (lower Manhattan, bridge and tunnel entrances, turnpike and arterial highway interchanges, etc.), fluctuatious in heavy traffic density are relatively small throughout the working day. Therefore, cumulative 8-hour exposures currently experienced by bus and taxi drivers, policemen, and workers in shops and offices within 50 to 100 feet of these congested points probably exceed the tentative air quality objective of 30 ppm for 8 hours and may, in fact, exceed 8-hour concentrations of 15 ppm more than 15 percent of the time at some locations as well. Dosages of CO totalling 240 ppm-hr can result in inactivation of 5 percent of the human body's ability to transport oxygen in the blood stream,[47/] very possibly producing injurious effects in sensitive persons (cardio-respiratory or anemia patients) who already suffer from reduced oxygen-carrying capacity. Such individuals may tolerate extended exposures to a CO concentration of 5 ppm more easily than to higher levels; a concentration of 5 ppm would reduce oxygen transport ability about 1 percent.

There is evidence of threshold effects on mental processes when 1 to 2 percent of hemoglobin is inactivated as carboxyhemoglobin.[48/] One to two percent carboxyhemoglobin is produced by 8-hour exposures to CO at concentrations of about 5 to 10 ppm.

Reduction in oxygen transport ability may result from causes other than pollution in ambient air. Carbon monoxide air pollution should therefore not be permitted to use all of the reserve capacity of susceptible people. Based on the effects of CO on mental processes and the presence in the population of persons with respiratory impairment, an air pollution goal limiting long-term CO exposures to the order of 5 ppm may eventually be judged acceptable.

EMISSION INVENTORY

Sulfur Oxides

Based on this survey, 1,590,000 tons of sulfurous air contaminants (calculated as SO_2) are discharged to the atmosphere annually from sources in the study area. In Table XXII, emissions are listed by source category for each county. These figures show that in the nine New Jersey counties 757,000 tons of SO_2 per year are generated and New York City contributes 735,000 tons per year; the counties of Westchester, Nassau, and Rockland together account for 99,200 tons annually.

For the purposes of this inventory, all sulfurous air contaminants were calculated as sulfur dioxide (SO_2). In fact, SO_2 does constitute over 97 percent of the total. Most of the remainder is discharged as sulfur trioxide or sulfuric acid mist. Hydrogen sulfide and other sulfides and mercaptans, although quite odorous and troublesome at times, contribute only minor weight fractions of total sulfur pollution. In the following discussion, for convenience, all sulfurous air contaminants collectively are termed sulfur oxides, or SO_x.

Although several types of sources in the study area discharge SO_x to the atmosphere, by far the largest quantity (95%) is generated from combustion of sulfur-bearing coal and oil (Tables XXIII and XXIV and Figure 18). Of the remaining 5 percent contributed by other sources, industrial process emissions account for the largest fraction (62,000 tons per year, or 3.9% of the total SO_x). Motor vehicles and refuse incineration are relatively minor sources, contributing respectively 0.9 and 0.2 percent of the study area total.

Combustion of bituminous coal and residual oil account for 84 percent of the SO_x emissions in the study area; 10 percent is derived from distillate oil, and 1.6 percent from anthracite coal. Combustion of natural gas does not produce significant emissions of SO_x.

Quantities of fuels burned in each county of the study area are listed in Table XXV. Annual use is: 4.86 billion gallons of residual oil, 3.68 billion gallons of distillate oil, 10.7 million tons of bituminous coal, 2.07 million tons of anthracite coal, and 408 billion cubic feet of natural gas. Burning of bituminous coal and residual oil, the major SO_x contributors, collectively provide 50 percent of the heat. Burning of the cleaner fuels - distillate oil, anthracite coal, and natural gas - provides the remaining 50 percent, but the three latter fuels are responsible for only 12 percent of the SO_x emissions.

Inventory SO_x totals reflect both fuel quantities and sulfur contents. Average sulfur contents of anthracite coal and distillate oil are 0.625 and 0.575 percent, respectively, whereas bituminous coal averages 1.875 percent sulfur and residual oil 2.45 percent. At any particular source, the fuel sulfur content can be markedly different from the average.

Steam-powered electricity-generating power plants contribute 39 percent of the total SO_x emitted in the study area; industrial fuel burning and process sources account for 22 percent; residential fuel burning contributes 21 percent; and commercial and governmental sources 17 percent.

The principal reason for delineating sources of fuel burning is to ascertain the variation in emissions with space heating requirements. Most of the domestic, commercial, and governmental

TABLE XXII

SULFUR OXIDES EMISSIONS IN THE NEW YORK-NEW JERSEY STUDY AREA (tons/year)

Area	Domestic Fuel						Commercial and Governmental Fuel					
	Bit. Coal	Ant. Coal	Dist. Oil	Res. Oil	Nat. Gas	Total	Bit. Coal	Ant. Coal	Dist. Oil	Res. Oil	Nat. Gas	Total
Bergen	972	323	9,287	571	6	11,159	960	15	527	11,777	2	13,281
Essex	1,120	3,448	11,465	2,079	4	18,116	2,672	24	1,348	28,784	1	32,829
Hudson	578	1,733	7,423	693	4	10,431	2,978	4	1,130	25,016	1	29,129
Middlesex	227	686	5,265	40	3	6,221	249	-	751	17,312	1	18,313
Monmouth	157	471	4,957	42	4	5,631	108	-	240	2,652	1	3,001
Morris	171	517	3,498	21	1	4,208	710	-	372	7,131	Neg.	8,213
Passaic	410	1,230	4,476	199	3	6,318	1,076	8	497	9,280	1	10,862
Somerset	86	264	1,903	10	1	2,264	323	119	221	4,271	Neg.	4,934
Union	496	1,484	6,525	383	3	8,891	2,231	5	761	17,959	1	20,957
New Jersey Total	4,217	10,156	54,799	4,038	29	73,239	11,307	175	5,847	124,182	8	141,519
Bronx	238	1,506	5,612	42,048	2	49,406	375	519	2,189	12,513	1	15,597
Brooklyn	144	1,854	20,498	45,457	9	67,962	236	840	6,490	35,054	2	42,622
Staten Island	14	82	1,212	2,874	2	4,184	38	378	655	1,412	Neg.	2,483
Manhattan	346	2,193	777	77,718	1	81,035	375	804	1,395	16,611	2	19,187
Queens	81	470	17,549	23,404	6	41,510	112	394	4,791	23,006	2	28,305
New York City Total	823	6,105	45,648	191,501	20	244,097	1,136	2,935	15,520	88,596	7	108,194
Nassau	-	547	13,005	-	3	13,555	2	25	1,947	2,411	1	4,386
Rockland	-	57	323	-	2	382	303	2	144	383	1	833
Westchester	-	513	5,385	5,550	2	11,450	800	37	2,449	4,565	3	7,854
Outer New York Total	-	1,117	18,713	5,550	7	25,387	1,105	64	4,540	7,359	5	13,073
New York Total	823	7,222	64,361	197,051	27	269,484	2,241	2,999	20,060	95,955	12	121,267
Study Area Total	5,040	17,378	119,160	201,089	56	342,723	13,548	3,174	25,907	220,137	20	262,786

TABLE XXII [continued]

SULFUR OXIDES EMISSIONS IN THE NEW YORK-NEW JERSEY STUDY AREA 1965 (tons/year)

Area	Process	Refuse Disposal	Mobile Sources			Total Non-Fuel	Industrial Fuel, Excluding Power Plants						Power Plants			
			Gasoline	Diesel	Total		Bit. Coal	Ant. Coal	Dist. Oil	Res. Oil	Nat. Gas	Total	Bit. Coal	Res. Oil	Nat. Gas	Total
Bergen	68	52	842	365	1,207	1,327	5,447	-	706	11,992	1	18,146	46,013	-	3	46,016
Essex	3,269	12	792	293	1,085	4,366	3,559	-	1,756	29,992	1	35,308	5,367	8,187	1	13,555
Hudson	156	114	391	162	553	823	2,550	1,058	1,469	32,076	1	37,154	59,053	11,318	-	70,371
Middlesex	30,155	20	395	393	788	30,963	6,594	1,548	1,005	36,760	4	45,911	58,489	29,412	3	87,904
Monmouth	-	7	335	321	656	663	1,163	-	387	6,630	1	8,181	-	-	-	-
Morris	-	11	281	241	522	533	833	-	411	6,982	Neg.	8,226	-	-	-	-
Passaic	25	4	334	220	554	583	1,163	655	548	11,233	1	13,600	-	-	-	-
Somerset	4,413	3	111	997	1,108	5,524	3,566	1,339	247	4,212	1	9,365	-	-	-	-
Union	23,617	14	504	230	734	24,365	2,539	25	1,258	32,814	3	36,639	-	42,602	-	42,602
New Jersey Total	61,703	237	3,985	3,222	7,207	69,147	27,414	4,625	7,787	172,691	13	212,530	168,922	91,519	7	260,448
Bronx	-	207	364	200	564	771	750	-	273	3,398	Neg.	4,421	-	22,552	3	22,555
Brooklyn	-	830	549	308	857	1,687	789	-	1,073	22,759	1	24,622	14,406	45,683	Neg.	60,089
Staten Island	-	4	80	58	138	142	38	-	263	2,608	Neg.	2,909	13,367	678	-	14,045
Manhattan	-	772	633	304	937	1,709	750	-	408	6,508	1	7,667	84,228	34,027	7	118,262
Queens	-	103	1,060	627	1,687	1,790	563	-	567	16,196	1	17,327	44,791	60,182	9	104,982
New York City Total	-	1,916	2,686	1,497	4,183	6,099	2,890	-	2,584	51,469	3	56,946	156,792	163,122	19	319,933
Nassau	30	390	1,048	211	1,259	1,679	996	3	518	2,533	Neg.	4,050	11,250	22,265	4	33,519
Rockland	-	26	166	27	193	219	990	3	30	1,650	Neg.	2,673	6,525	1	1	6,527
Westchester	11	219	768	126	894	1,124	5,022	9	550	533	Neg.	6,114	-	4,835	-	4,835
Outer New York Total	41	635	1,982	364	2,346	3,022	7,008	15	1,098	4,716	Neg.	12,837	17,775	27,101	5	44,881
New York Total	41	2,551	4,668	1,861	6,529	9,121	9,898	15	3,682	56,185	3	69,783	174,567	190,223	24	364,814
Study Area Total	61,744	2,788	8,653	5,083	13,736	78,268	37,312	4,640	11,469	228,876	16	282,313	343,489	281,742	31	625,262

Area	Total Fuel Burning						Grand Total
	Bit. Coal	Ant. Coal	Dist. Oil	Res. Oil	Nat. Gas	Total	
Bergen	53,392	338	10,520	24,340	12	88,602	89,929
Essex	12,718	3,472	14,569	69,042	7	99,808	104,174
Hudson	65,159	2,795	10,022	69,103	6	147,085	147,908
Middlesex	65,559	2,234	7,021	83,524	11	158,349	189,312
Monmouth	1,428	471	5,584	9,324	6	16,813	17,476
Morris	1,714	517	4,281	14,134	1	20,647	21,180
Passaic	2,649	1,893	5,521	20,712	5	30,780	31,363
Somerset	3,975	1,722	2,371	8,493	2	16,563	22,087
Union	5,266	1,514	8,544	93,758	7	109,089	133,454
New Jersey Total	211,860	14,956	68,433	392,430	57	687,736	756,883
Bronx	1,363	2,025	8,074	80,511	6	91,979	92,750
Brooklyn	15,575	2,694	28,061	148,953	11	195,294	196,981
Staten Island	13,457	460	2,130	7,572	2	23,621	23,763
Manhattan	85,699	2,997	2,580	134,864	11	226,151	227,860
Queens	45,547	864	22,907	122,788	18	192,124	193,914
New York City Total	161,641	9,040	63,752	494,688	48	729,169	735,268
Nassau	12,248	575	15,470	27,209	8	55,510	57,189
Rockland	7,818	62	497	2,034	4	10,415	10,634
Westchester	5,822	559	8,384	15,483	5	30,253	31,377
Outer New York Total	25,888	1,196	24,351	44,726	17	96,178	99,200
New York Total	178,529	10,236	88,103	539,414	65	825,347	834,468
Study Area Total	399,389	25,192	156,536	931,844	122	1,513,083	1,591,351

Table XXIII

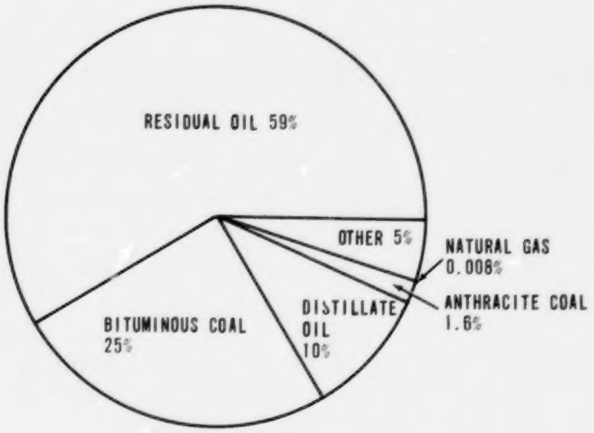
CONTRIBUTIONS OF SOURCE CATEGORIES TO SULFUR OXIDE EMISSIONS IN MAJOR SUBDIVISIONS OF STUDY AREA, 1965

Source Category	Fraction SO_x Contributed, % of total			
	New Jersey	New York City	Outer New York Counties	Study Area
Miscellaneous				
Industrial Processes	8.2	Neg.	< 0.1	3.9
Refuse Incineration	< 0.1	0.3	0.6	0.2
Motor Vehicles	1.0	0.6	2.4	0.9
Misc. Subtotal	9.2	0.9	3.0	5.0
Combustion Fuels				
Industrial	28	8	13	18
Power Plants	34	42	45	39
Domestic	10	34	26	21
Govt. and Comm.	19	15	13	17
Fuel Subtotal	91	99	97	95
Total SO_x, tons per year	756,883	735,268	99,200	1,591,351

Table XXIV

CONTRIBUTIONS OF COMBUSTION FUELS TO SULFUR OXIDE EMISSIONS IN MAJOR SUBDIVISIONS OF STUDY AREA, 1965

Fuel	Fraction SO_x Contributed, % of total			
	New Jersey	New York City	Outer New York Counties	Study Area
Residual Oil	52	68	45	59
Bituminous Coal	28	21	26	25
Distillate Oil	9.1	8.8	25	10
Anthracite Coal	2.0	1.2	1.2	1.6
Natural Gas	0.008	0.007	0.02	0.008
Combustion Fuel Subtotal	91	99	97	95
Combustion Fuel SO_x, tons per year	687,737	729.169	96,178	1,513,083



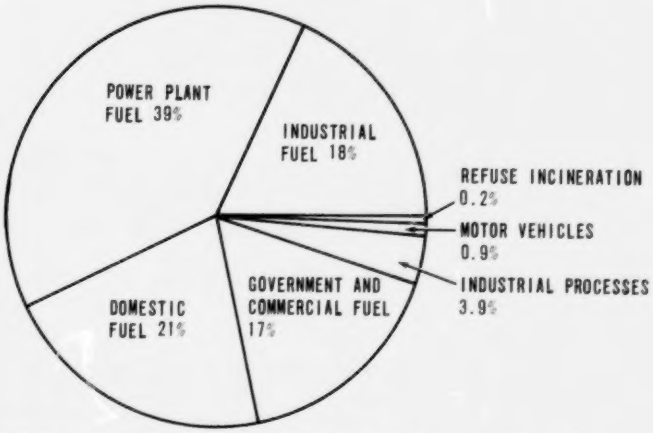


Figure 18. Sulfur oxides emitted in the total study area (top) by various fuels and (bottom) by various sources.

fuel is burned during the winter for space heating; smaller quantities are used in other periods for cooking, air conditioning, and water heating. Fuel usage, and hence emissions, from power plants and industrial sources are relatively constant throughout the year. On a minimum space-heating day, power plants and industrial sources are the principal emitters of sulfur compounds. In colder periods of the year, space heating increases SO_x discharges appreciably.

The pattern of fuel usage in New Jersey, New York City, and the outlying New York counties, depicted in Table XXVI, reflects the concentration of large residential apartment buildings in New York City, the suburban character of the outer New York counties, and the greater industrialization in New Jersey.

In New York City, 99 percent of the SO_x emissions are attributed to combustion of fuels. There are no significant process sources in the city, but electrical power generation accounts for 43 percent of its SO_x. Many apartment buildings are heated with residual oil. Residential fuel burning generates 34 percent of the annual total SO_x, but during maximum space-heating days

TABLE XXV

FUEL BALANCE IN THE NEW YORK - NEW JERSEY STUDY AREA, 1965

Area	Industrial Fuel - Excluding Power Plants					Domestic Fuel Use					Power Plants		
	Coal, tons		Fuel Oil, 1,000's of gal		Nat. Gas millions of ft^3	Coal, tons		Fuel Oil, 1,000's of gal		Nat. Gas millions of ft^3	Bituminous Coal, tons	Residual Fuel Oil, 1,000's of gal	Nat. Gas, millions of ft^3
	Bituminous	Anthracite	Distillate	Residual		Bituminous	Anthracite	Distillate	Residual				
J-1 Bergen	145,249	-	16,612	61,496	3,862	8,612	77,791	218,526	2,927	20,590	931,436	-	9,630
J-2 Essex	94,900	-	41,326	153,806	4,628	29,876	275,835	269,761	10,660	13,861	112,987	39,656	1,585
J-3 Hudson	68,000	84,646	34,552	164,493	3,214	15,408	138,628	174,662	3,555	12,891	1,169,306	54,824	-
J-4 Middlesex	175,827	123,854	23,651	188,512	14,721	6,048	54,874	123,871	205	10,553	1,215,141	148,021	9,263
J-5 Monmouth	31,008	-	9,104	33,998	2,800	4,193	37,667	116,639	217	12,970	-	-	-
J-6 Morris	22,202	-	9,680	35,803	1,332	4,557	41,384	82,312	105	4,305	-	-	-
J-7 Passaic	31,020	52,395	12,903	57,605	2,112	10,934	98,371	105,306	1,019	10,289	-	-	-
J-8 Somerset	95,100	107,100	5,800	21,600	1,690	2,296	21,154	44,781	49	2,883	-	-	-
J-9 Union	67,700	2,000	29,607	168,275	9,676	13,215	118,685	153,529	1,965	8,690	-	233,310	-
New Jersey Total	731,006	369,995	183,235	885,588	44,035	95,139	864,389	1,289,387	20,702	96,982	3,428,870	475,811	20,478
Y-1 Bronx	20,000	-	6,427	17,425	1,230								
Y-2 Brooklyn	21,037	-	25,246	116,713	3,040	6,343	120,507	132,056	215,629	7,520	-	122,438	9,546
Y-3 Staten Island	1,000	-	6,185	13,372	506	3,847	148,300	482,305	233,111	29,535	432,200	253,512	793
Y-4 Manhattan	20,000	-	9,597	33,376	3,346	365	6,554	28,525	14,738	4,922	669,700	3,948	-
Y-5 Queens	15,000	-	13,341	83,057	2,515	9,221	175,422	18,288	398,552	4,823	2,232,900	185,052	24,779
						2,170	37,556	412,912	120,018	21,367	1,916,600	320,630	30,124
New York City Total	77,037	-	60,796	263,943	10,637	21,946	488,339	1,074,086	982,048	68,167	5,251,400	885,580	65,242
Y-6 Nassau	26,556	211	12,178	12,991	983	-	43,752	306,001	-	8,507	300,000	114,181	13,801
Y-7 Rockland	26,400	235	700	8,462	103	-	4,578	7,606	-	6,431	174,000	4	2,769
Y-8 Westchester	133,928	745	12,935	27,350	461	-	41,037	126,693	28,461	5,687	-	24,904	-
Outer New York Total	186,884	1,191	25,813	48,803	1,547	-	89,367	440,300	28,461	20,625	474,000	139,089	16,570
New York Total	263,921	1,191	86,609	312,746	12,184	21,946	577,706	1,514,386	1,010,509	88,792	5,725,400	1,024,669	81,812
Study Area Total	994,927	371,186	269,844	1,198,334	56,219	117,085	1,442,095	2,803,773	1,031,211	185,774	9,154,270	1,500,480	102,290

Area	Commercial & Govenmental					Total Fuel Use					Traffic	
	Coal, tons		Fuel Oil. 1,000's of gal		Nat. Gas, millions of ft^3	Coal, tons		Fuel Oil, 1,000's of gal		Nat. Gas, millions of ft^3	1,000's of gal	
	Bituminous	Anthracite	Distillate	Residual		Bituminous	Anthracite	Distillate	Residual		Gasoline	Diesel
J-1 Bergen	25,599	1,204	12,390	60,395	5,658	1,110,896	78,995	247,528	124,818	39,740	336,580	16,213
J-2 Essex	71,247	1,912	31,686	147,608	4,636	309,010	277,747	342,773	351,730	24,710	316,900	13,004
J-3 Hudson	79,402	339	26,589	128,288	3,645	1,332,116	223,613	235,803	351,160	19,750	156,400	7,214
J-4 Middlesex	6,650	-	17,681	88,781	1,980	1,403,666	178,728	165,203	425,519	36,517	157,816	17,451
J-5 Monmouth	2,883	-	5,637	13,601	1,705	38,084	37,667	131,380	47,816	17,475	133,967	14,270
J-6 Morris	18,929	-	8,753	36,570	1,150	45,688	41,384	100,745	72,478	6,787	112,345	10,703
J-7 Passaic	28,681	617	11,698	47,592	2,279	70,635	151,383	129,907	106,216	14,680	133,636	9,772
J-8 Somerset	8,620	9,523	5,202	21,903	607	106,016	137,777	55,783	43,552	5,130	44,310	7,655
J-9 Union	59,496	375	17,914	92,099	1,978	140,411	121,060	201,050	495,649	20,344	201,550	10,237
New Jersey Total	301,507	13,970	137,550	636,837	23,638	4,556,522	1,248,354	1,610,172	2,018,938	185,133	1,593,504	106,519
Y-1 Bronx	10,000	41,508	51,501	64,170	2,851	36,343	162,015	189,984	419,662	21,147	145,586	8,908
Y-2 Brooklyn	6,300	67,202	152,701	179,762	6,341	463,384	215,502	660,252	783,098	39,709	233,836	13,692
Y-3 Staten Island	1,000	30,248	15,417	7,240	1,057	672,065	36,802	50,127	39,298	6,485	32,006	2,558
Y-4 Manhattan	10,000	64,313	32,823	85,184	7,298	2,272,121	239,735	60,708	702,164	40,246	253,167	13,529
Y-5 Queens	3,000	31,525	112,734	117,980	5,306	1,936,770	69,081	538,987	641,685	59,312	424,113	27,872
New York City Total	30,300	234,796	365,176	454,336	22,853	5,380,683	723,135	1,500,058	2,585,907	166,899	1,078,708	66,559
Y-6 Nassau	56	2,020	45,818	12,365	4,390	326,612	45,983	363,997	139,537	27,681	419,071	9,387
Y-7 Rockland	8,075	155	3,393	1,965	1,561	208,475	4,968	11,699	10,431	10,864	66,299	1,209
Y-8 Westchester	21,332	2,926	57,617	23,412	11,204	155,260	44,708	197,245	104,127	17,352	307,165	5,612
Outer New York Total	29,463	5,101	106,828	37,742	17,155	690,347	95,659	572,941	254,095	55,897	792,535	16,208
New York Total	59,763	239,897	472,004	492,078	40,008	6,071,030	818,794	2,072,999	2,840,002	222,796	1,871,243	82,767
Study Area Total	361,270	253,867	609,554	1,128,915	63,646	10,627,552	2,067,148	3,683,171	4,858,940	407,929	3,464,747	189,286

Table XXVI

RELATIVE QUANTITIES OF PRINCIPAL FUELS USED IN MAJOR SUBDIVISIONS OF STUDY AREA, 1965

Fuel[a]	Fraction Heat Supplied, % of total			
	New Jersey	New York City	Outer New York Counties	Study Area
Residual Oil	34	41	19	36
Bituminous Coal	13	15	9	14
Distillate Oil	26	23	40	25
Anthracite Coal	4	2	1	3
Natural Gas	23	19	31	22
Gross Heat, Btu/year	889×10^{12}	951×10^{12}	203×10^{12}	$2{,}043 \times 10^{12}$

[a] Gross heating values: Residual oil,152,000 Btu/gal; distillate oil, 142,000 Btu/gal; bituminous and anthracite coal, 26,000,000 Btu/ton: natural gas, 1,100 Btu/scf.

the SO_x generated is well in excess of the power plant total. In New York City, a greater proportion of residual oil is used to supply heating needs than in the other portions of the study area.

In the counties of Westchester, Rockland, and Nassau, natural gas and distillate oil supply 71 percent of the fuel heat, as compared to 49 percent in New Jersey and 42 percent in New York City. Automotive SO_x emissions in the outer counties are higher than the study area average, but they constitute only 2.4 percent of the three-county total.

Almost all of the process sources are located in New Jersey, where SO_x emissions from industrial fuel burning (for heat and process) account for 36 percent of the New Jersey SO_x total.

Steam-powered electricity-generating power plants, the largest source category in the study area, discharge 39 percent of the SO_x. Two firms, Consolidated Edison Company and Public Service Electric and Gas Company, generate over 80 percent of the electricity and SO_x emissions. Power plants consume significant portions of the high-sulfur-content fuels used in the area, i.e. 87 percent of the bituminous coal and 31 percent of the residual oil.

Electric utilities in all three major subdivisions of the study area use residual oil to supply about 40 percent of their fuel requirements (Table XXVII), but the relative quantities of bituminous coal and natural gas differ markedly. The outer New York counties use natural gas for 35 percent of their steam generation, whereas New York City uses 21 percent gas and New Jersey only 12 percent. New Jersey power plants use bituminous coal to supply 48 percent of their needs, as compared to 40 percent for New York City and 24 percent for the outer counties.

In addition to burning relatively more coal, New Jersey power plants utilize coal and oil of generally higher sulfur content. Residual oil burned by New Jersey utilities averages 2.4 percent sulfur, slightly more than the 2.3 percent in that burned in New York. There is a much greater difference in the sulfur content of coals burned: 1.56 percent for New York, and 2.58 percent for New Jersey.

Table XXVII

RELATIVE QUANTITIES OF PRINCIPAL FUELS USED BY
STEAM-ELECTRIC POWER PLANTS IN MAJOR SUBDIVISIONS
OF STUDY AREA, 1965

Fuel[a]	Fraction Heat Supplied, % of total				
	New Jersey	New York City	Outer New York Counties	Avg. New York	Study Area
Residual Oil	40	39	41	40	39
Bituminous Coal	48	40	24	38	41
Natural Gas	12	21	35	23	20
	100	100	100	100	100
Gross Heat Input, Btu/year	185×10^{12}	342×10^{12}	51×10^{12}	393×10^{12}	578×10^{12}

[a] Gross heating values: Residual oil, 152,000 Btu/gal: bituminous coal 26,000,000 Btu/ton: and natural gas 1,100 Btu/scf.

Because of the higher sulfur fuels burned in New Jersey power plants, their sulfur emissions are relatively greater for the quantity of electricity produced. In the New York State portion of the study area, about 9 tons of sulfur oxides are discharged to the atmosphere for every million kilowatt-hours of electricity; in northeastern New Jersey, 13 tons of sulfur oxides are emitted for every million kilowatt-hours.

Industrial process sources in the study area produce 62,000 tons of sulfurous emissions per year. Over 97 percent of the total is discharged as SO_2, the rest as sulfur trioxide and sulfuric acid mist. These contaminant releases represent 3.9 percent of the area total and 8.2 percent of the annual total in the New Jersey portion, where almost all process sources are located. About 50 percent of the 62,000 tons is discharged from sulfuric acid plants, 30 percent from petroleum refineries, and 20 percent from miscellaneous chemical plants, foundries, and other operations. Most of the industrial sources are concentrated in coastal areas along the Arthur Kill and Raritan River. About one-third of the total process sulfur emissions is emitted from a single zone in Linden. The largest single process source discharges 18,000 tons of SO_x per year, in addition to the 5,200 tons per year generated by its fuel burning.

Process industries that discharge sulfur dioxide and sulfuric acid mist to the atmosphere are nominally well controlled. All except one of the sulfuric [illegible]d plants appear to be operating with a conversion rate to sulfur trioxide of 96 to 98 percent. The acid processes are equipped with filters and precipitators to control acid mist, but no SO_2 control devices are employed. It is significant that the acid manufacturer with the lowest conversion rate (92-94%) also discharges the largest quantity of SO_2. Concentrations of SO_2 in exhaust gases from acid plants range from 2,000 to 4,000 ppm, whereas concentrations in stack gases from boilers burning residual fuel oil range from 1,200 to 1,600 ppm.

Most of the process SO_x attributed to refineries is discharged from catalyst regenerators. These refinery gases contain approximately the same concentrations of SO_x as residual fuel oil combustion products. All three of the operating refineries in the area utilize sulfur-recovery processes to convert some waste gases to sulfuric acid.

One of the larger chemical plants now discharging sulfur compounds (4,400 tons per year) to the atmosphere reportedly is planning to install a sulfur-recovery process in the near future.

The preceding estimates of air contaminant discharges from process sources represent conditions when the processes are operated under what plant officials consider "normal" conditions. These conditions are, in fact, optimum from the air pollution control standpoint. They represent the situation when there are no upset conditions, rated production capacities are not exceeded, and all air pollution control equipment is operating at peak efficiency. No chemical processes can be expected to operate all the time under optimum conditions. Under upset conditions, production in excess of design capacities or malfunctions of control equipment, air contaminant emissions can be far in excess of normal levels. In a sulfuric acid plant, for instance, impaired catalysis can result in extremely large concentrations of SO_2 in exhaust gases.

The frequencies with which such breakdowns occur depend upon the vagaries of the process, design and maintenance of equipment, and diligence of workers. It is difficult to predict how often breakdowns will occur or what quantities of pollutants will be discharged before a breakdown is corrected.

Possibly, more common than breakdowns are instances of greater-than-normal contamination releases resulting from inefficient operation of air pollution control equipment. Since control devices often do not yield revenue or product, maintenance is likely to be neglected with resultant loss of efficiency.

Data compiled by the Interstate Sanitation Commission provide some insight into the situation. Concentrations of SO_2 were measured in areas downwind of major sources, including most of the refineries and chemical plants in the interstate area, and frequent instances of ground level values exceeding 1.0 ppm SO_2 were found. On one occasion, concentrations greater than 5 ppm were recorded downwind of an acid plant during upset conditions.

Increased fuel burning during days of maximum space heating causes SO_x emissions to increase threefold over those of minimum heating days. On a maximum heating day, 8,245 tons of SO_x are discharged to the atmosphere of the study area (Table XXVIII). Especially large increments in SO_x tonnages occur when space heating is required in the more heavily populated areas. For example, in Brooklyn, the space-heating increment is almost 1,000 tons on a maximum heating day, and in Manhattan, which is a much smaller area, the increase on a maximum heating day is over 700 tons of SO_x. The significant effect of space-heating sources is shown in Table XXIX.

Table XXVIII

EMISSIONS OF SULFUR OXIDES AND CARBON MONOXIDE FOR MINIMUM, AVERAGE, AND MAXIMUM SPACE-HEATING DAYS (tons/day)

	SULFUR OXIDES			CARBON MONOXIDE
	Min.	Avg	Max.	
Bergen	178	282	415	1,351
Essex	140	359	642	1,285
Hudson	288	466	695	641
Middlesex	437	560	718	1,062
Monmouth	23	56	98	538
Morris	23	76	145	452
Passaic	36	111	208	544
Somerset	38	72	115	187
Union	274	413	591	817
New Jersey Total	1,437	2,395	3,627	6,877
Bronx	109	328	610	603
Brooklyn	251	686	1,247	968
Staten Island	45	74	112	132
Manhattan	410	733	1,150	1,045
Queens	345	627	990	1,713
New York City Total	1,160	2,448	4,109	4,461
Nassau	112	180	268	1,677
Rockland	25	31	39	265
Westchester	38	110	202	1,230
Outer New York Total	175	321	509	3,172
New York Total	1,335	2,769	4,618	7,633
Study Area Total	2,777	5,164	8,245	14,510

Emission densities in Manhattan are far in excess of those in any other area; they range from 19 tons per square mile on a minimum heating day to 52 tons per square mile on a maximum heating day (Table XXX). The three other populous boroughs of New York City and Hudson County in New Jersey have sizeable emission densities during maximum heating days.

In Appendix E, zone totals are listed for minimum, average, and maximum degree-days. Individual zone densities can vary considerably from county averages. A source pattern usually can be determined from the ratio of minimum to maximum SO_x emissions. In zone of heavy industrial saturation,

Table XXIX

SOURCES OF SULFUR OXIDES AND CARBON MONOXIDE FOR MINIMUM, AVERAGE, AND MAXIMUM SPACEHEATING DAYS (tons/day)

New York-New Jersey-Study Area-1965

	SULFUR OXIDES			CARBON MONOXIDE
	Min.	Avg	Max.	
Refuse	8	8	8	57
Mobile Sources	38	38	38	13,868
Process	168	168	168	426
Industrial Fuel	615	850	1,153	20
Power Plants	1,712	1,712	1,712	13
Residential Fuel	231	1,300	2,677	106
Commercial and Governmental Fuel	-	1,088	2,489	20
Total	2,772	5,164	8,245	14,510

TABLE XXX

SULFUR OXIDES EMISSION DENSITIES FOR MINIMUM, AVERAGE, AND MAXIMUM SPACE HEATING DAYS

	SO_x Emission Densities, tons/day per mi^2		
County	Min. Day	Avg Day	Max. Day
New Jersey			
Bergen	0.8	1.2	1.8
Essex	1.1	2.8	5.1
Hudson	6.3	10.1	15.1
Middlesex	1.4	1.7	2.2
Monmouth	0.05	0.1	0.2
Morris	0.05	0.2	0.3
Passaic	0.2	0.6	1.1
Somerset	0.1	0.2	0.4
Union	2.7	4.0	5.8
New York			
Bronx	2.5	7.6	14.2
Brooklyn	3.3	9.0	16.4
Staten Island	0.8	1.2	1.9
Manhattan	18.6	33.3	52.3
Queens	3.1	5.5	8.8
Nassau	0.4	0.6	0.9
Rockland	0.1	0.2	0.2
Westchester	0.1	0.2	0.5

there is often little variation. Zone J-4-9 in Middlesex County is a heavily industrialized zone containing a power plant, an oil refinery, and several industrial plants. Its maximum day emission density of 52.3 tons per square mile is only 5 percent higher than the minimum day density. In most zones, there is a much greater variation with space-heating demands. Maximum variations with space heating occur in Manhattan where some zones show daily minimum to maximum degree-day increments greater than 60 tons per square mile.

Zones containing steam-powered plants or other large point sources have markedly greater emissions than adjacent zones that are otherwise similar. Some of the variations in zone totals are due to the manner in which the zones were established. In most of New York City, each zone contains 1 square mile or less, whereas those in surrounding New York State counties and in New Jersey generally are larger. If a large point source, such as a steam-powered electric plant, is located in a zone of 1 square mile, the zone total becomes extremely large. An example is zone Y-2-6 in Brooklyn, only 0.2 square mile in area, it contains a power plant and has an emission density over 700 tons per square mile per day. If the same power plant were located in a zone of 6 or 7 square miles, the resultant emission density would be much smaller. For this reason, data contained in Appendix E must be considered in light of point source emissions.

There are in the study area 373 sources, each of which discharges 100 or more tons of SO_x per year. These point sources include power plants and major industrial sources, as well as commercial, governmental, and residential buildings. Of the total, 79 percent discharge 100 to 500 tons per year; 12 percent 500 to 1000 tons; 9 percent 1,000 to 4000 tons; and 10 percent more than 4,000 tons of SO_x per year. Power plants make up two-thirds of the over-4000-ton category, and industrial sources the rest. The 373 point sources discharge 841,000 tons of SO_x, more than half of the area total.

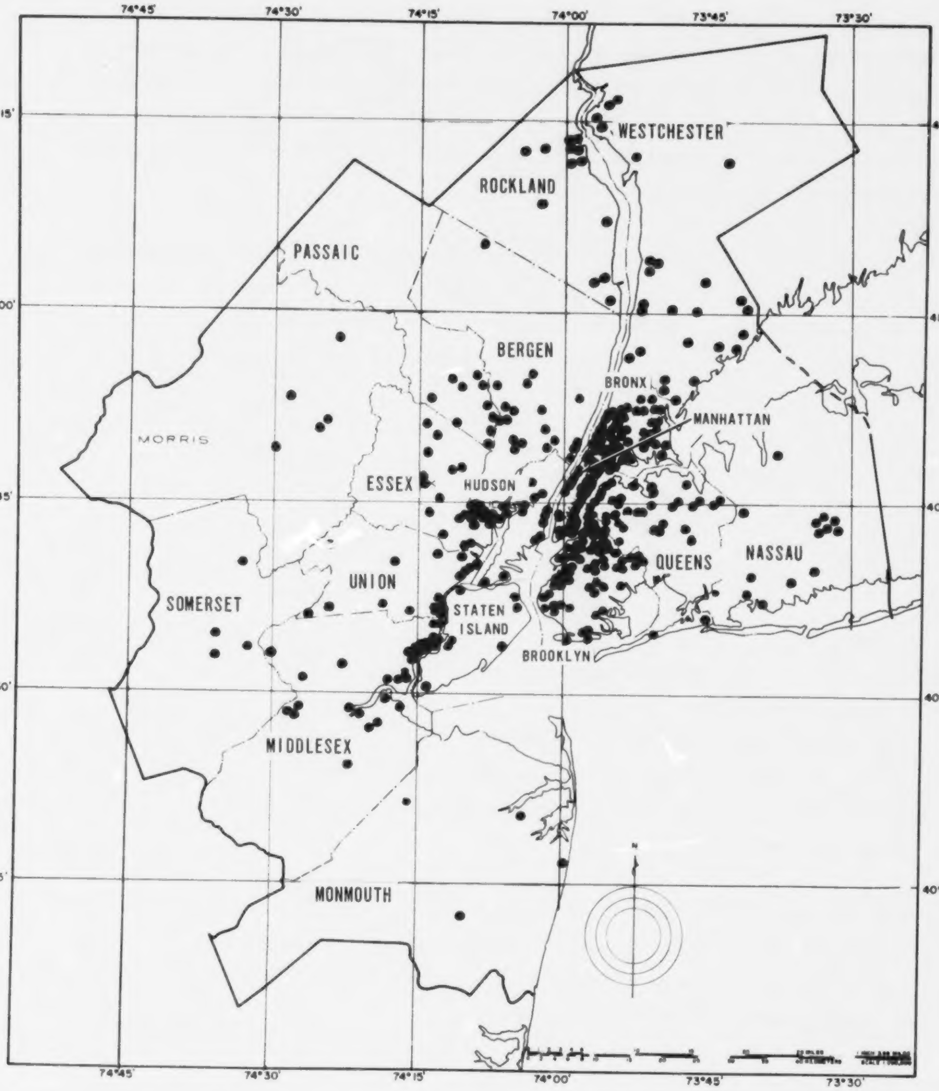
Point sources that discharge 100 or more tons of SO_x each year are plotted in Figure 19. A large percentage are located in proximity to, and on both sides of, the state line. The 34 largest point sources are shown on the maps in Figures 20, 21, and 22 where SO_x emission concentrations are shown for minimum, average, and maximum heating days.

Carbon Monoxide

The abatement activity survey showed that 5,296,000 tons of carbon monoxide (CO) are discharged to the atmosphere of the study area annually. Over 95 percent of this total is generated by gasoline-fueled motor vehicles. In New York, the motor vehicle fraction exceeds 99 percent.

The only significant nonvehicular sources of CO are industrial processes in New Jersey, which discharge about 3 percent of the annual total (Table XXXI). Only 1.1 percent of the total orginates from the combustion of heating fuels, primarily anthracite coal burned for residential space heating. Diesel-powered vehicles account for only 0.1 percent and refuse incineration 0.4 percent of the total.

Zones of greatest CO emissions generally are located in the four most heavily populated boroughs of New York City, but high CO discharge values are also found in some zones of Nassau, Westchester, Essex, and Hudson Counties (Figure 23). Emission concentrations of CO are highest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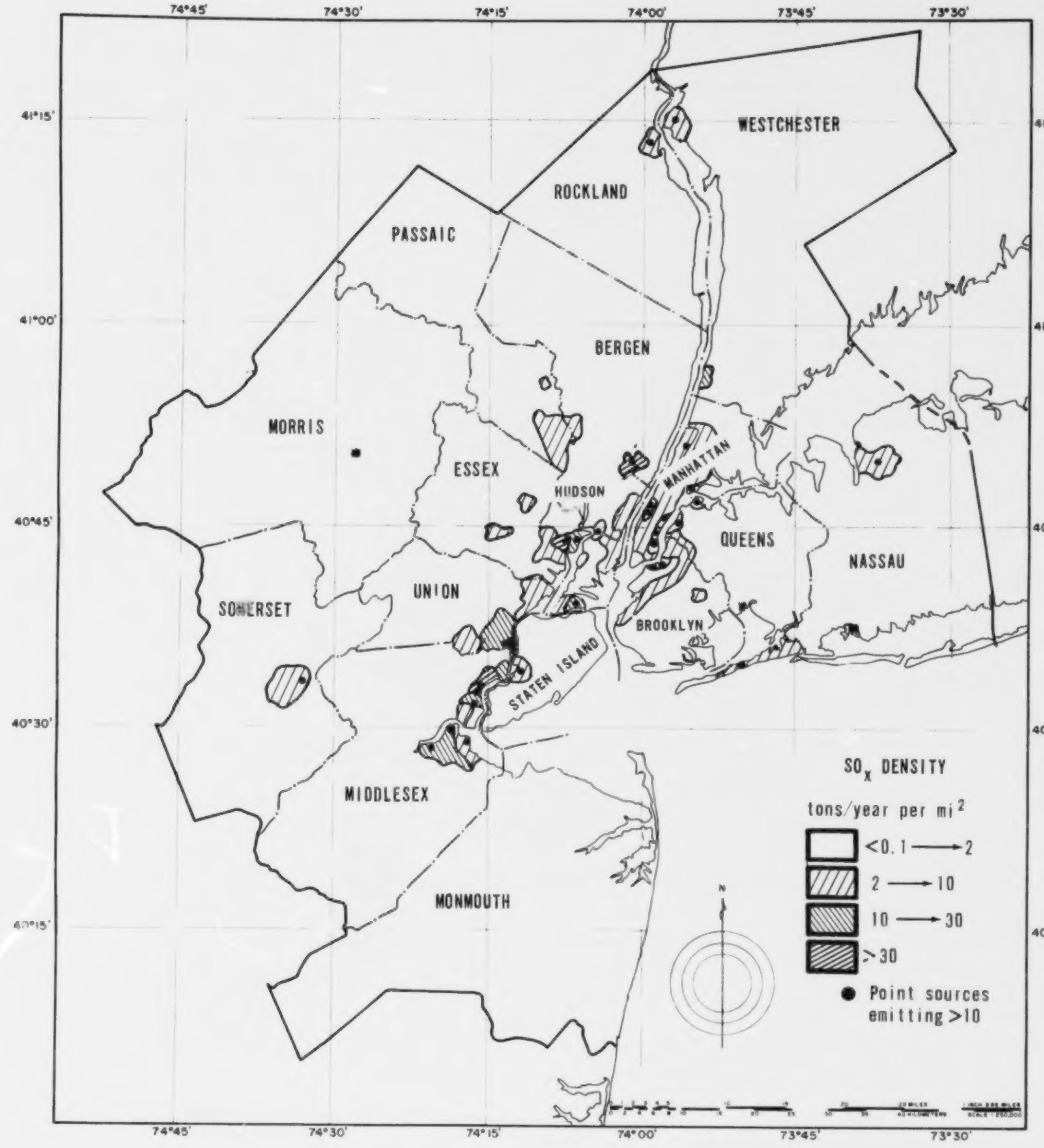
PASSAIC
BERGEN
BRONX
MANHATTAN
MORRIS
ESSEX
HUDSON
QUEENS
NASSAU
UNION
SOMERSET
STATEN ISLAND
BROOKLYN
MIDDLESEX
MONMOUTH
N

Figure 19. Distribution of point sources that emit more than 100 tons of SO_x each year.

in Manhattan, where values in several zones exceed 60 tons per day per square mile. Middlesex County zones, in which petroleum refinery catalyst regenerators are located, have densities of 64 and 134 tons per day per square mile. Carbon monoxide emissions are considered to be essentially constant throughout the year, although measurable increases may occur during the heating season from inefficient small combustion units.

In determining CO emissions, it was assumed that all gasoline sold in a county also was consumed there. It is probable, however, based on comparison of gasoline sales and vehicle-mile data that much of the gasoline sold in the counties of Bergen, Essex, Hudson, and Union is consumed elsewhere, most likely in Middlesex County and New York City.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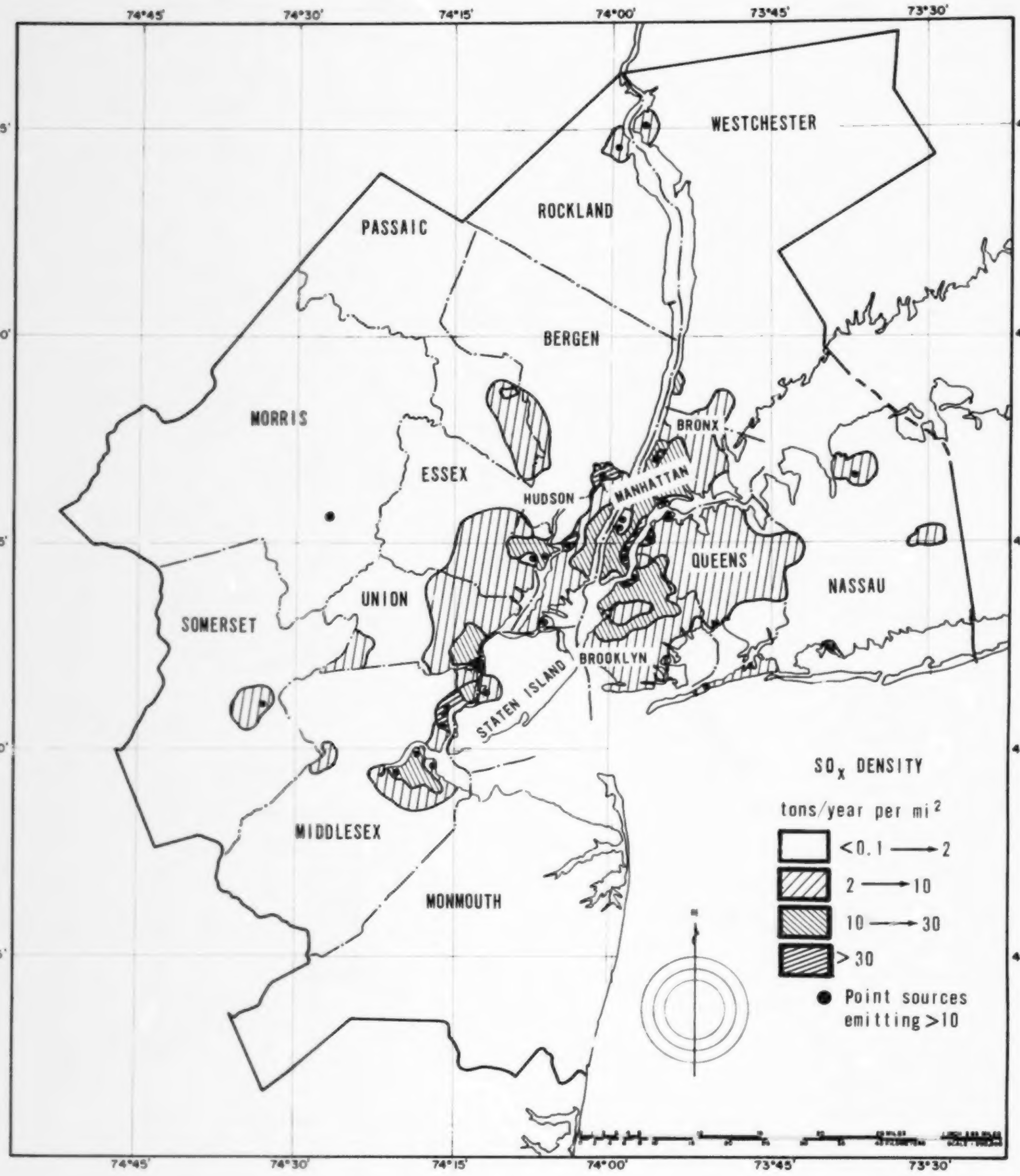
QUEENS
NASSAU
UNION
SOMERSET
BROOKLYN
STATEN ISLAND
MIDDLESEX
MONMOUTH
N
SO_x DENSITY
tons/year per mi^2
<0.1 → 2
2 → 10
10 → 30
>30
● Point sources emitting >10

Figure 20. Sulfur oxides emission densities for a minimum space-heating day in 1965.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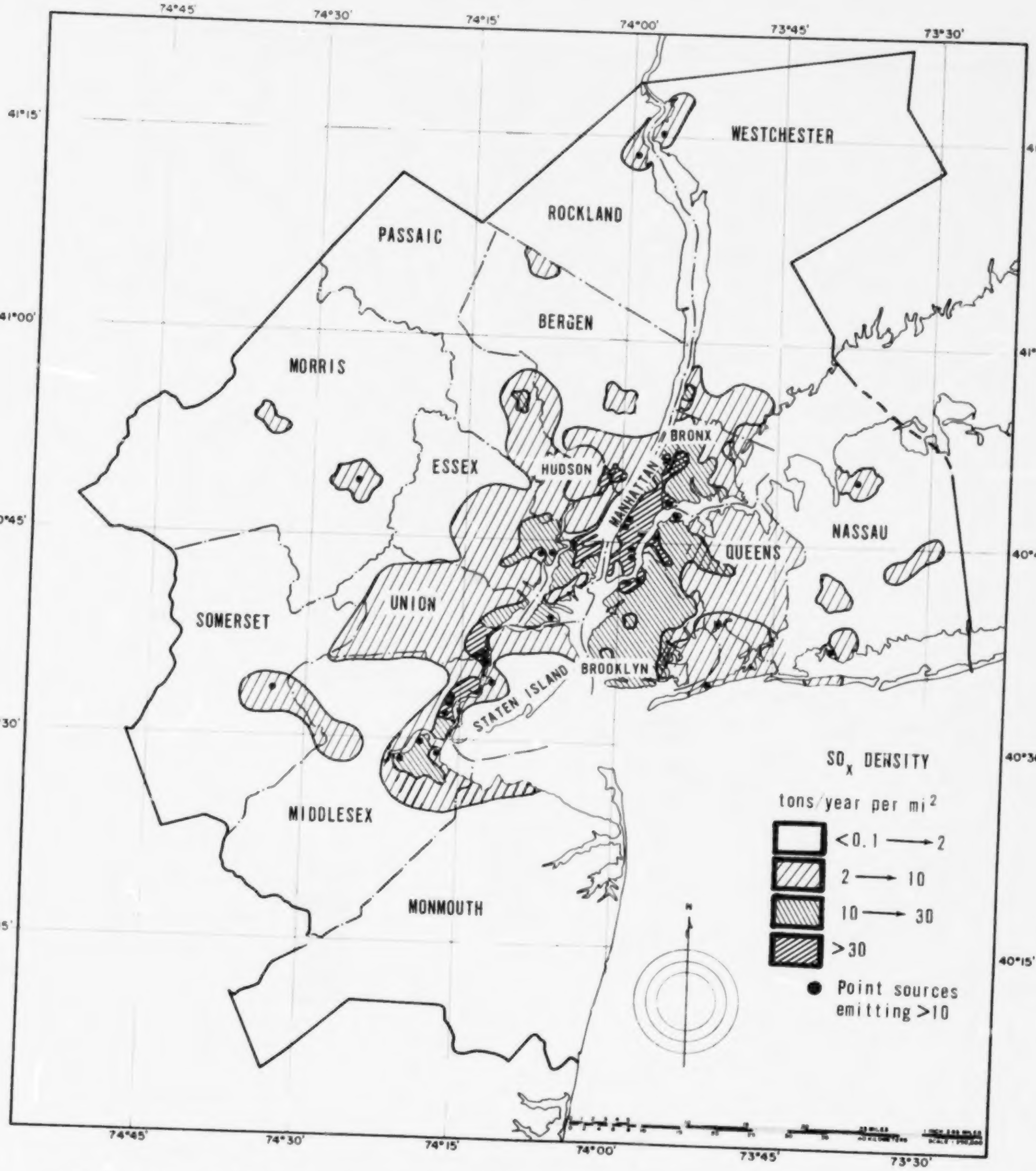
MANHATTAN
BRONX
QUEENS
NASSAU
UNION
SOMERSET
BROOKLYN
STATEN ISLAND
MIDDLESEX
MONMOUTH
SO$_X$ DENSITY
tons/year per mi^2
<0.1 → 2
2 → 10
10 → 30
> 30
● Point sources emitting >10

Figure 21. Sulfur oxides emission densities for an average space-heating day in 1965.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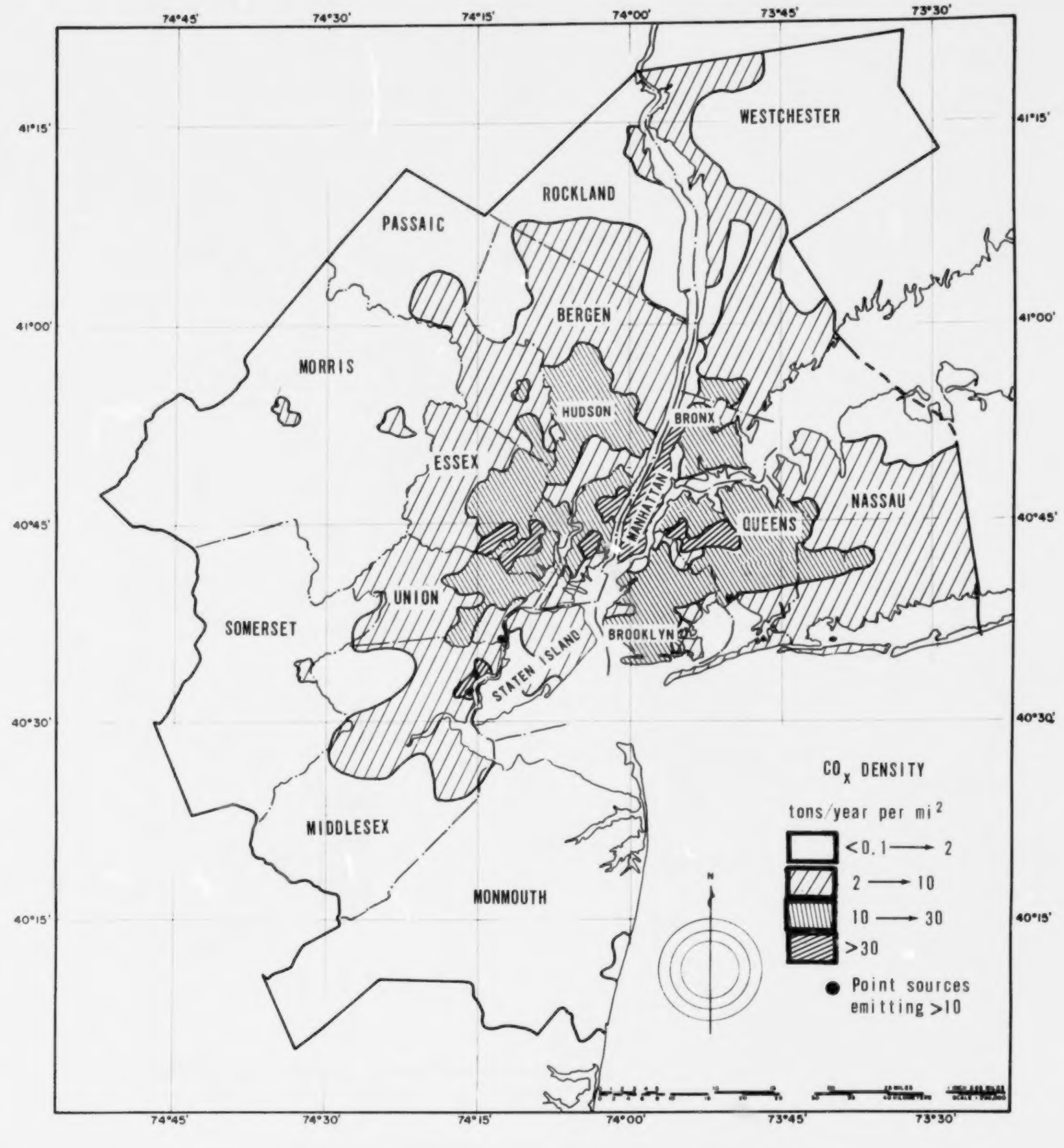
HUDSON
BRONX
MANHATTAN
NASSAU
QUEENS
UNION
SOMERSET
BROOKLYN
STATEN ISLAND
MIDDLESEX
MONMOUTH
N
SO$_X$ DENSITY
tons/year per mi^2
<0.1 → 2
2 → 10
10 → 30
>30
● Point sources emitting >10

Figure 22. Sulfur oxides emission densities for a maximum space-heating day in 1965.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BRONX
ESSEX
MANHATTAN
NASSAU
QUEENS
UNION
SOMERSET
STATEN ISLAND
BROOKLYN
MIDDLESEX
MONMOUTH
N
CO_x DENSITY
tons/year per mi^2
<0.1 ⟶ 2
2 ⟶ 10
10 ⟶ 30
>30
● Point sources emitting >10

Figure 23. Carbon monoxide emission densities for an average day in 1965.

Table XXXI

CARBON MONOXIDE EMISSIONS
(tons/year)

Area	Process	Industrial Fuel	Domestic Fuel	Comm. & Govt. Fuel	Power Plants	Refuse Disposal	Total Non-Vehicular	Mobile Sources		Total Vehicular	Grand Total
								Gasoline	Diesel		
Bergen	-	90	2,173	56	468	10	2,797	489,724	487	490,211	493,008
Essex	-	90	7,187	138	57	76	7,548	461,090	390	461,480	469,028
Hudson	-	1868	3,651	73	585	71	6,248	227,562	216	227,778	234,026
Middlesex	154,700	540	1,482	24	610	49	157,405	229,622	524	230,146	387,551
Monmouth	-	25	1,073	5	-	Neg.	1,103	194,922	428	195,350	196,453
Morris	-	37	1,120	19	-	22	1,198	163,462	321	163,783	164,981
Passaic	-	1,338	2,524	41	-	54	3,957	194,440	293	194,733	198,690
Somerset	-	2,729	575	245	-	5	3,554	64,471	230	64,701	68,255
Union	850	133	3,118	74	-	350	4,525	293,255	307	293,562	298,087
New Jersey Total	155,550	6,850	22,903	675	1,720	637	188,335	2,318,548	3,196	2,321,744	2,510,079
Bronx	-	40	3,146	1,024	2	3,868	8,080	211,828	267	212,095	220,175
Brooklyn	-	39	4,161	1,834	216	5,969	12,219	340,231	821	341,052	353,271
Staten Island	-	6	193	771	335	321	1,626	46,569	77	46,646	48,272
Manhattan	-	20	4,359	1,658	1,121	5,582	12,740	368,358	406	368,764	381,504
Queens	-	22	1,353	1,283	964	3,772	7,394	617,084	836	617,920	625,314
New York City Total	-	127	13,212	6,570	2,638	19,512	42,059	1,584,070	2,407	1,586,477	1,628,536
Nassau	-	30	1,392	178	153	337	2,090	609,748	282	610,030	612,120
Rockland	-	102	105	15	88	17	327	96,465	36	96,051	98,828
Westchester	-	99	1,152	163	-	413	1,827	446,925	168	447,093	448,920
Outer New York Total	-	231	2,649	356	241	767	4,244	1,153,138	486	1,153,624	1,157,868
New York Total	-	358	15,861	6,926	2,879	20,279	46,303	2,737,208	2,893	2,740,101	2,786,404
Study Area Total	155,550	7,208	38,764	7,601	4,599	20,916	234,638	5,055,756	6,089	5,061,845	5,296,483

Almost all of the process CO is emitted from two catalyst regenerators at petroleum refineries in Middlesex County, which together account for over 150,000 tons per year of CO, two-thirds of the nonvehicular total. A waste heat boiler reportedly will be installed at one of the refineries in the near future to eliminate most of the CO in exhaust gases.

REPRESENTATIVENESS OF SAMPLING PERIOD

June, July and August 1966 comprised the hottest and driest summer on record in New York. In a statement issued Sept. 1, 1966, Anthony E. Tancrito, Meteorologist-in-Charge, U.S. Weather Bureau, New York, New York, said:

> "The past three months recorded an average temperature of 77.3 degrees making it the hottest summer since records were established in 1869, the previous being in 1949 when the average was 76.9 degrees. During this past summer temperatures of 90 degrees or higher were recorded on 34 days setting a new record, the previous being 33 days during the summer months.
>
> This record breaking warm period also saw a record low in rainfall. Only 4.31 inches fell during the three months compared to a normal of 11.45 inches. This set a new record for the summer months, the previous having occurred in 1894 when 4.36 inches fell during the like period."

During the summer, temperatures were above normal at all U.S. Weather Bureau stations in the New York area. Temperatures exceeded the normals by 2.5°F at Central Park, but only by 0.3°F at J.F. Kennedy International Airport. The airport is located on Jamaica Bay, less than 3 miles from the Atlantic Ocean; hence, it is exposed to a greater extent than is Central Park to the sea breeze, which accounts for this temperature difference. A maximum temperature of 90°F or above was experienced only 13 days at the airport during the summer, in contrast to 34 days at Central Park.

Inversions during the summer of 1966 occurred much more frequently than the average for the summers of 1960-64. Summer is the season when inversions below 1,000 meters are least frequent. They were observed on 47 percent of the upper air observations during the summers of 1960-64, but during the summer of 1966, on 65 percent of the observations. The departure in 1966 from the 1960-64 average was accounted for by the greater frequency of ground based inve[illegible]able XXXII).

TABLE XXXII

PERCENTAGE FREQUENCY OF INVERSIONS WITH BASES BETWEEN INDICATED ALTITUDE RANGES AT J.F. KENNEDY INTERNATIONAL AIRPORT
(twice daily observations at 7 a.m. and 7 p.m.)

	Summer 1966	Average Summer 1960-64
Ground Based	33	16
6-150 m (20-494 ft)	8	7
151-500 m (495-1642 ft)	17	18
501-1000 m (1643-3282 ft)	7	6
Total 0-1000 m (surface -3282 ft)	65	47

The greater frequency of ground-based inversions in 1966 is compatible with the slightly below average wind speed and the markedly below average cloud cover, which in Central Park between sunrise and sunset averaged 46 percent coverage versus a normal of 56 percent coverage. Ground-based inversions are most likely to occur when there are few clouds.

Average wind speeds were less, but only slightly, than the long period normal at the New York stations. None averaged more than 0.6 mile per hour less than normal. Newark, however, was windier than normal by about 1.7 miles per hour. Surface wind directions were more southerly or southwesterly and less southeasterly, than average (Figures 24 through 27). Winds at 1000 feet were more westerly than average (Figures 11 and 28).

The number of days with precipitation was markedly below normal. On the average, the New York area has measurable rainfall 1 day in 3 during the summer, but measurable rain fell on 1 day in 5 during the summer of 1966. The total rainfall was less than 40 percent of normal.

A precise evaluation of the occurrence of stagnation situations was not practicable; however, Central Park's average daily wind speed data show four periods of 4 or more consecutive days when the average daily wind speeds were 7 miles per hour or less. Three of the periods had frontal systems pass or approach and were eliminated. On six of the eight upper air observations taken during the remaining period, July 21 through 24, inversions were observed below 500 meters, and there were definite symptoms of a stagnation period developing on these days. According to Donnelly, 19 stagnation periods occurred in the summer months during the 63-year period 1899-1962 (Table IX). The expectancy, then, is one stagnation period approximately every three summers.

In summary, wind speeds were lighter than normal at most points: inversions were more frequent than normal; precipitation was much less than normal; and, during one 96-hour period, wind speeds were so light and inversions so prevalent that stagnation conditions were suggested. On the other hand, the extremely high temperatures of the 1966 summer, which occurred in record number, were conducive to excellent ventilation. The pollutants must have been mixed through a deep layer on most afternoons. The hot weather also was conducive to sea breezes, which would tend to bring relatively pollution-free air from the ocean over the area.

Although weather conditions appeared to be less favorable than average for rapid dispersal of pollutants, it is a matter of conjecture whether the meteorological factors were sufficiently abnormal to affect the average concentrations of pollutants significantly. At any rate, deviations from seasonal average air quality levels were not apparent at the 121st Street Station of the New York City Department of Air Pollution Control (Figures 14 and 15).

DEMONSTRATION OF INTERSTATE TRANSPORT

The atmosphere recognizes no political boundaries. Wind can transport airborne contaminants from county-to-county, city-to-city, and state-to-state. Interstate transport of pollutants in the New York - New Jersey metropolitan area has been demonstrated on several occasions. Three such specific demonstrations are discussed here.

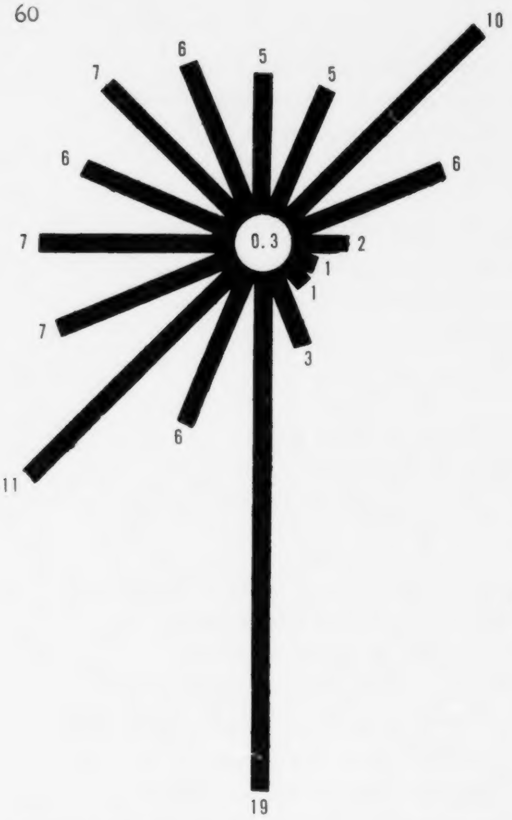
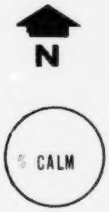


Figure 24. Percentage frequency of surface wind direction during June, July, August 1966 at LaGuardia Airport.



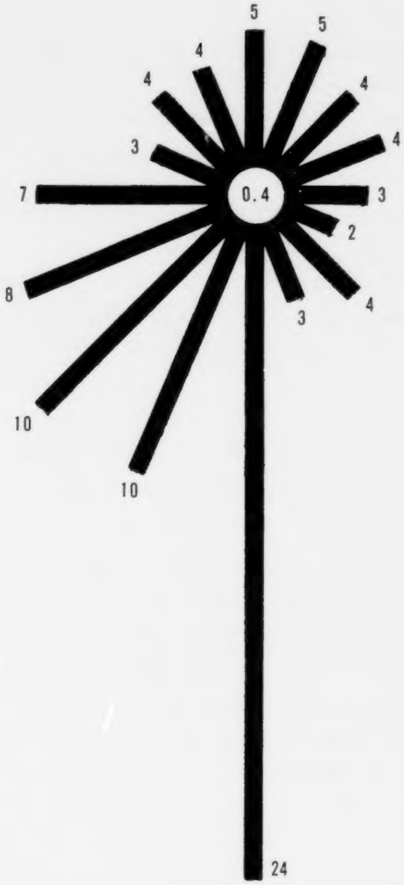


Figure 25. Percentage frequency of surface wind direction during June, July, August 1966 at J. F. Kennedy International Airport.

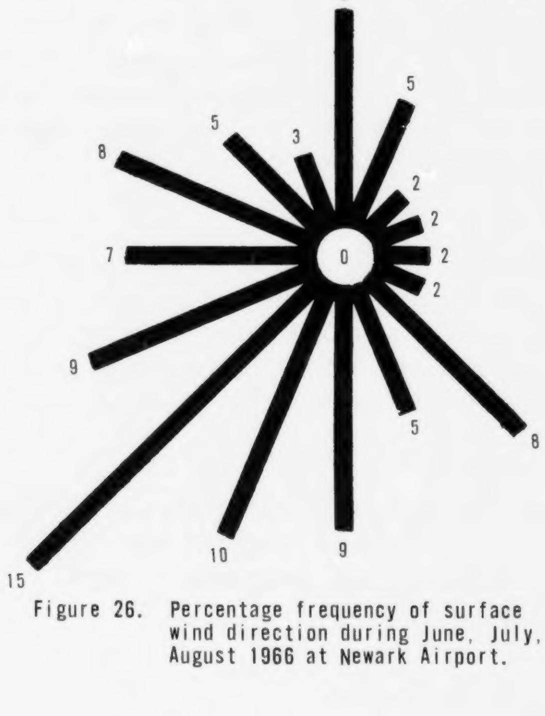


Figure 26. Percentage frequency of surface wind direction during June, July, August 1966 at Newark Airport.

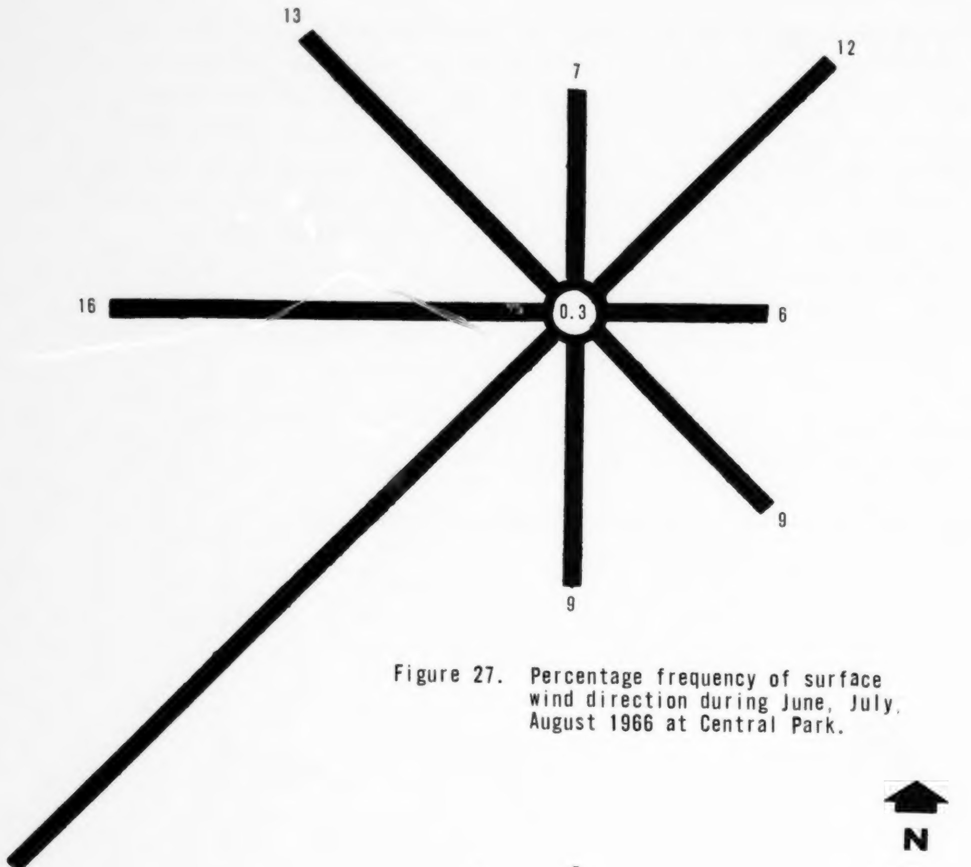


Figure 27. Percentage frequency of surface wind direction during June, July, August 1966 at Central Park.

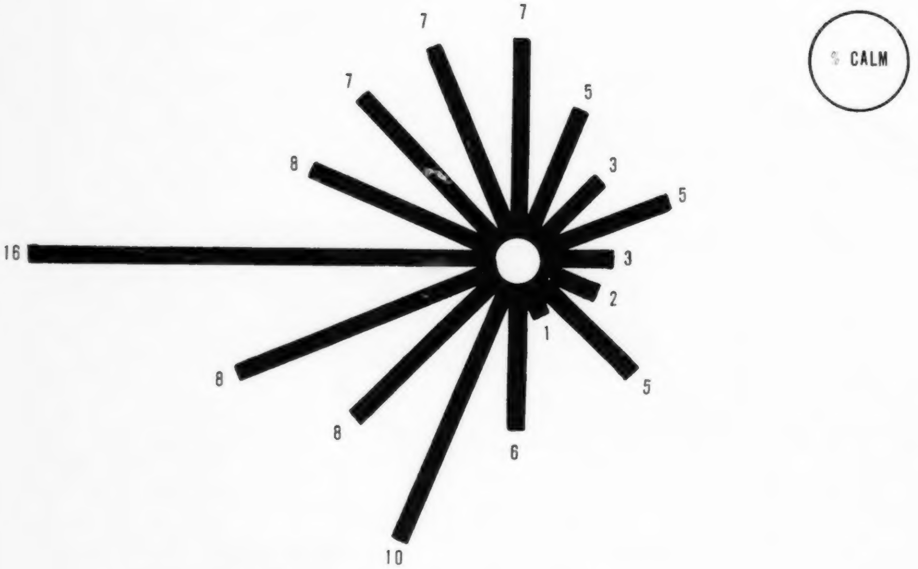
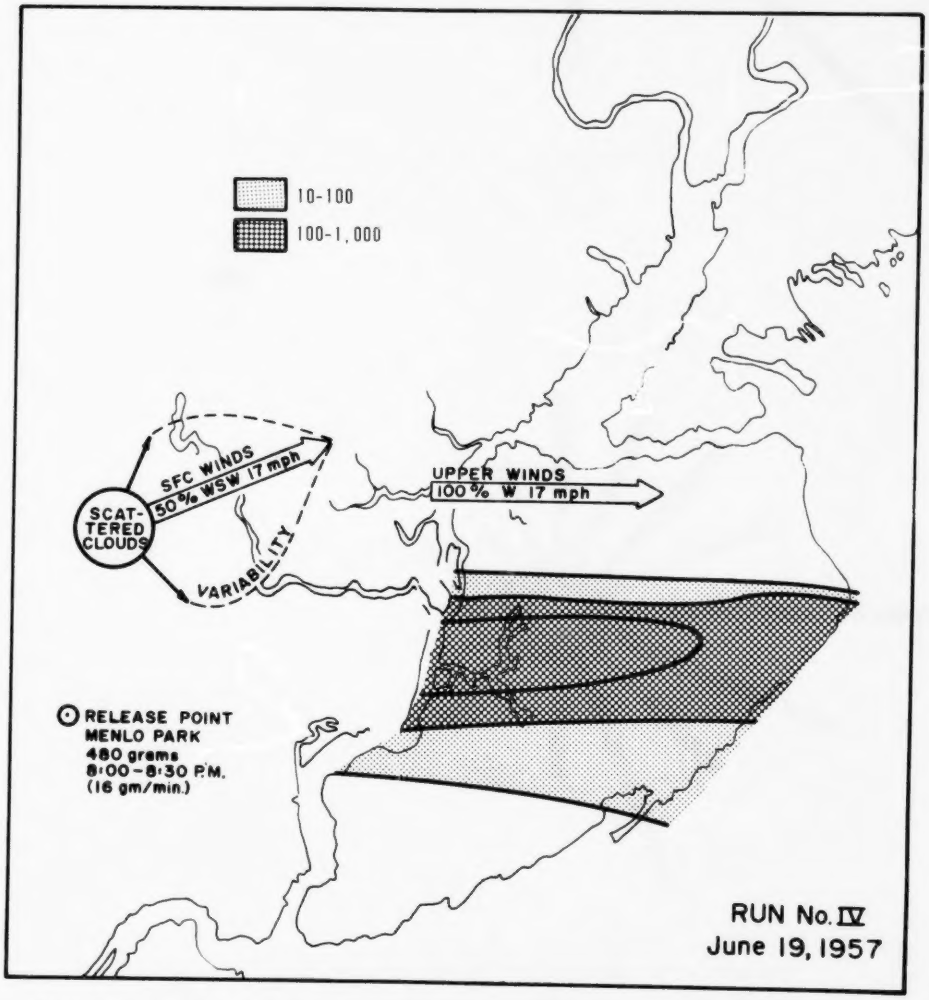


Figure 28. Percentage frequency of wind directions at 1,000-foot elevation during June, July, August 1966 at J. F. Kennedy International Airport--observations at 7 a.m. and 7 p.m.

A series of experiments were conducted by the Interstate Sanitation Commission during the summer and fall of 1957.[49/] Small amounts of microscopic-sized fluorescent zinc cadmium sulfide particles, commonly referred to as FP (fluorescent particles), were released near ground level at various points in the metropolitan area. The particles act as tracers. Earlier studies had indicated that FP behaves similarly to the molecules of the air mass in which they are entrained Therefore, it was reasonable to expect that the dispersal and transport of actual air contaminants would be analogous to the tracer particles. In each experimental release of tracer material, an array of sampling or collection points was located in the state other than the one in which the particles were released. The periods for release of tracer particles were chosen when the wind was expected to have an appropriate direction to show that interstate transportation of pollutants would occur.

Figures 29 and 30 show the pattern of the plume of tracer material across Staten Island when the release points were in New Jersey. Figures 31 and 32 show the distribution of particles



10-100
100-1,000
SCAT-TERED CLOUDS
SFC WINDS
50% WSW 17 mph
VARIABILITY
UPPER WINDS
100% W 17 mph
⊙ RELEASE POINT
MENLO PARK
480 grams
8:00-8:30 P.M.
(16 gm/min.)
RUN No. IV
June 19, 1957

Figure 29. Dispersal patterns of fluorescent particles, June 19, 1957.

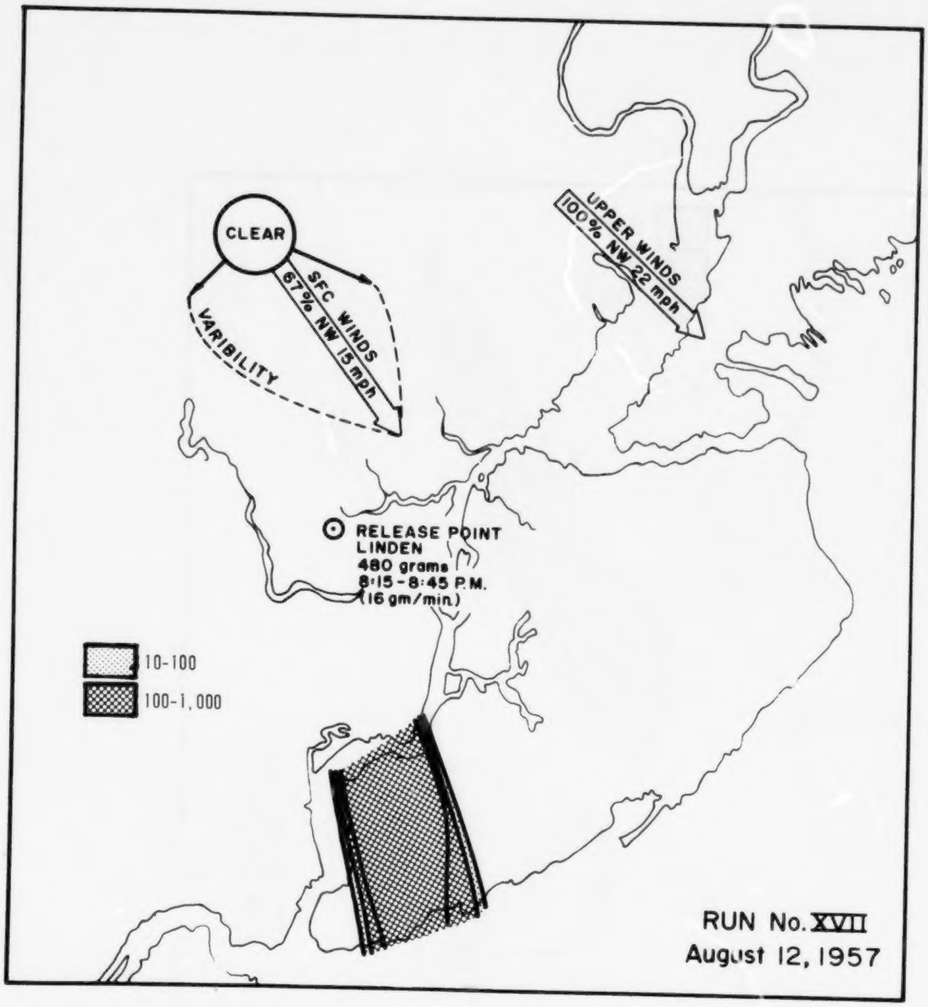

CLEAR
SFC WINDS
67% NW 15 mph
VARIBILITY
UPPER WINDS
100% NW 22 mph
RELEASE POINT
LINDEN
480 grams
8:15-8:45 P.M.
(16 gm/min.)
10-100
100-1,000
RUN No. XVII
August 12, 1957

Figure 30. Dispersal pattern of fluorescent particles, August 12, 1957.

collected in New Jersey when the release point was at Gansevoort Street on the lower west side of Manhattan.

The experiments clearly demonstrated that contaminants released at ground level do cross state lines. Significant quantities of the tracer material released in New Jersey were collected in New York. Similarly, when the particles were released in New York, they were recovered in New Jersey.

A tetroon is a super-pressure, constant-volume ballon that when properly inflated with a mixture of helium and air will float near a selected level. The term "tetroon" was coined from the tetrahedral shape of the plastic balloon, (Figure 33). The tetroon carries a beacon that allows its geographical position to be determined by means of an appropriately modified weather radar system. Thus, the balloon-radar-beacon system can provide a mechanism for tracing air currents that transport and dilute air contaminants.

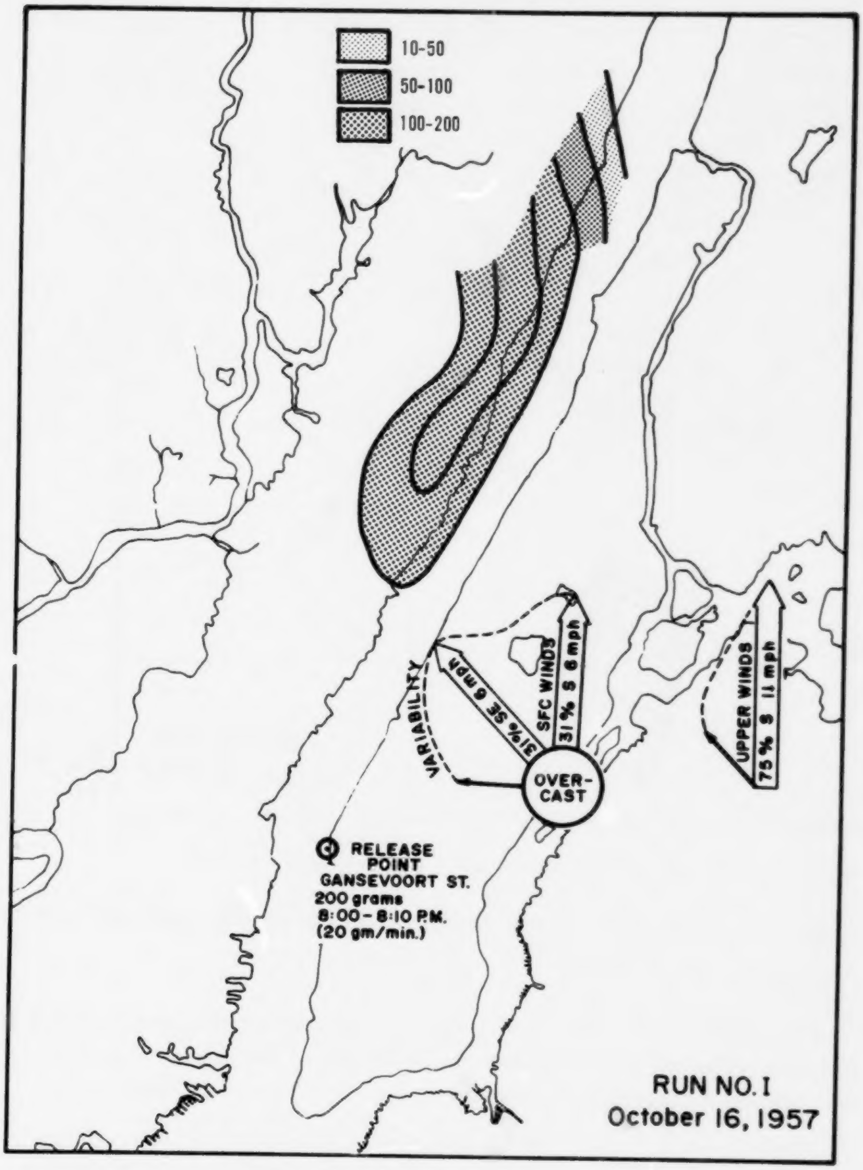

10-50
50-100
100-200
VARIABILITY
31% SE 6 mph
SFC WINDS
31% S 6 mph
OVER-CAST
UPPER WINDS
75% S 11 mph
RELEASE POINT
GANSEVOORT ST.
200 grams
8:00 - 8:10 P.M.
(20 gm/min.)
RUN NO. I
October 16, 1957

Figure 31. Dispersal pattern of fluorescent particles, October 16, 1957

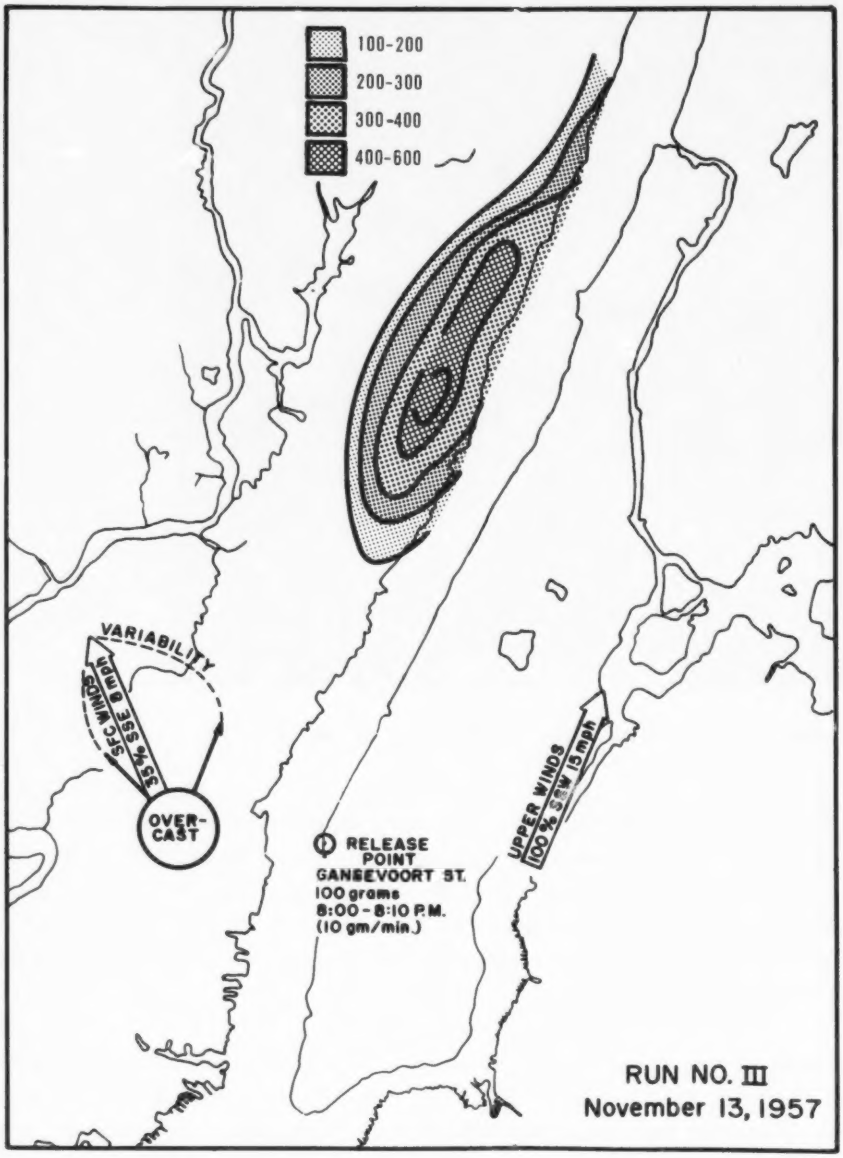

100-200
200-300
300-400
400-600
VARIABILITY
SFC WINDS
35% SSE 8 mph
OVER-CAST
RELEASE POINT
GANSEVOORT ST.
100 grams
8:00 - 8:10 P.M.
(10 gm/min.)
UPPER WINDS
100% SSW 15 mph
RUN NO. III
November 13, 1957

Figure 32. Dispersal pattern of fluorescent particles, November 13, 1957.

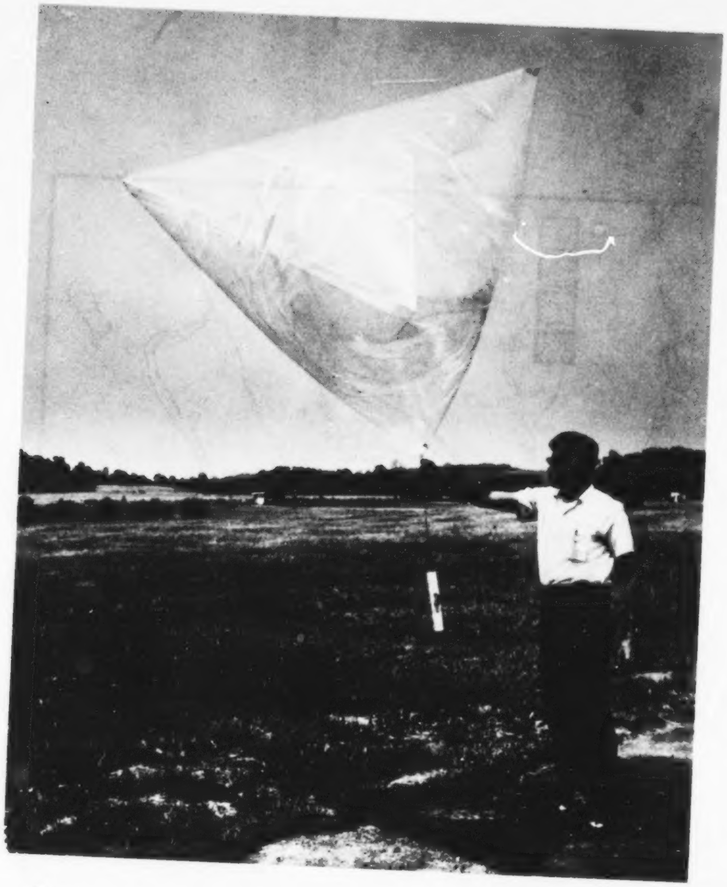


Figure 33. Tetroon ready for launch (USWB photograph).

During June 1965, the U.S. Weather Bureau and New York University collaborated on a study to test the feasibility of using the system in a complex urban area to obtain data on air trajectories influencing the distribution of air pollution in the New York - New Jersey metropolitan area.[50] The studies showed that air currents cross - and often recross - state boundaries. Further, under the influence of the sea breeze, the air currents, and presumably, the path of airborne particles, become extremely complicated.

Fifty-five tetroons were released during the period June 7 through 21, 1965. All were designed to float at 500 feet, an elevation at which pollutants from slightly elevated sources often are effectively discharged and, under many meteorological conditions, transported. Some of the flights were followed by aircraft to ascertain whether the tetroons did, in fact, float at the desired altitude. From the aircraft data, it was learned that a large percentage of the flights probably exceeded the design-altitude by a considerable margin; however, a number remained well within the design limits, and most remained sufficiently close to the ground to trace the air currents that are instrumental in the distribution of air contaminants from a variety of sources.

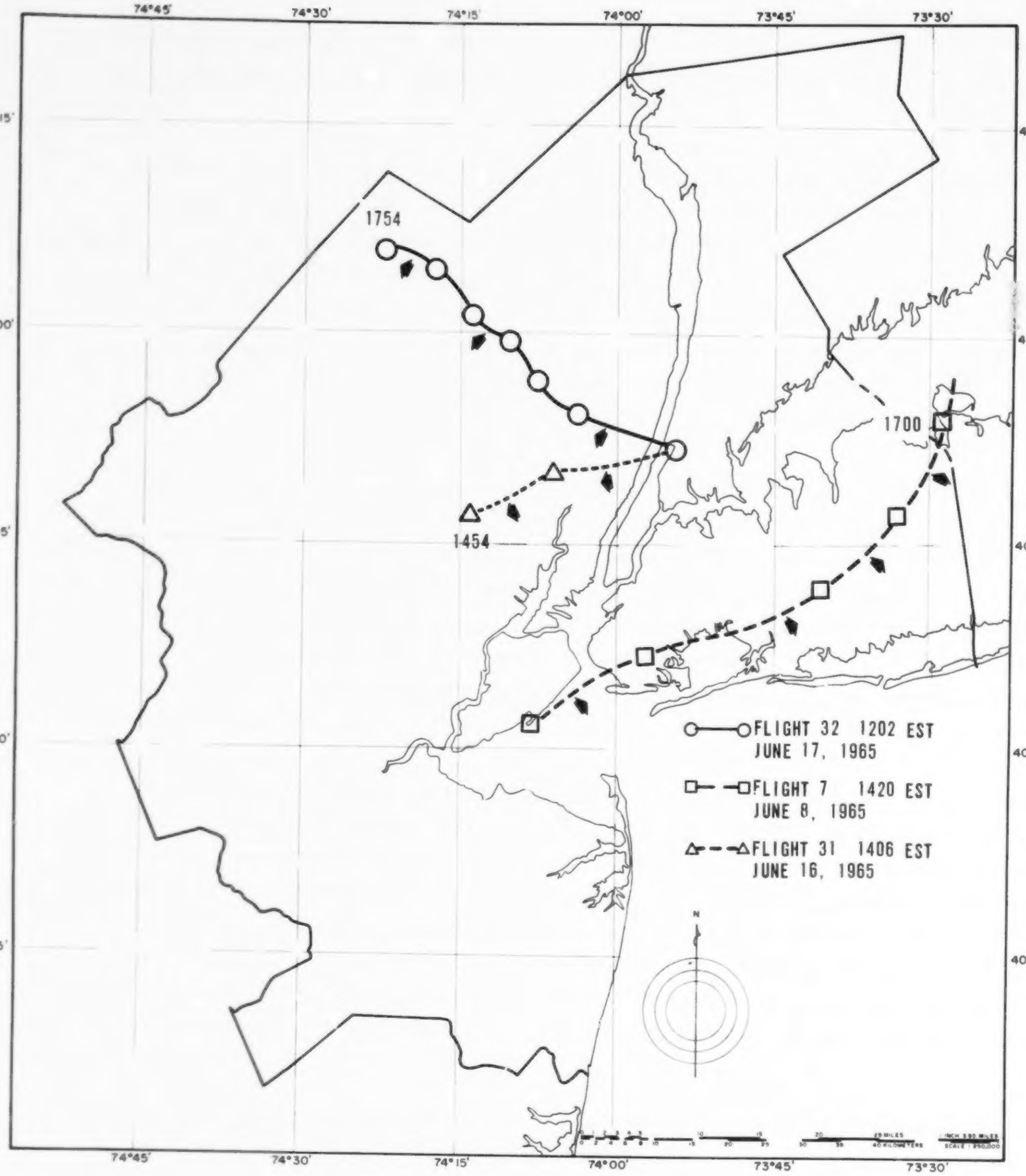
Five launch points were used: two in New Jersey and one each in the Bronx, Queens, and Staten Island. Another release point was desired in the Raritan Bay - Arthur Kill area; and in Manhattan. Great Kills Park, Staten Island, was the site nearest the Arthur Kill-Raritan Bay region that afforded ample clearance for release of a tetroon, and convenient access, and to which reliable communications could be maintained. It was expected that releases from this site would provide data similar to the trajectories of air parcels passing over the industrial complexes near Raritan Bay.

The trajectories indicate that a great variety of paths of air parcels may be anticipated in the New York - New Jersey metropolitan area. Under appropriate meteorological conditions, the tetroons passed rapidly from New Jersey across Manhattan, Queens, Brooklyn, and to the Atlantic, Long Island Sound, or New England. On other occasions, tetroons launched in Queens or Bronx moved steadily across Manhattan into New Jersey (Flights 31 and 32, Figure 34). But most intriguing, on frequent occasions tetroons released in either New York or New Jersey crossed state lines, milled randomly, then recrossed state boundaries (sometimes passing near their release point) several hours after they were launched.

Data gathered on June 12, 1965, provide striking examples of such occurrences. Three tetroons were released during early morning hours: Flight 21 from a point in the Bronx at 0437 EST; Flights 22 and 24 from the New Jersey Meadows at 0718 EST and 0928 EST, respectively. Flights 22 and 24 were last observed floating over Westchester County in the late afternoon, but they took quite different routes to reach there (Figure 35). Meanwhile, as Flights 22 and 24 entered Westchester, Flight 21, launched in New York, was last observed 6 miles west of Newark Airport. As shown in Figure 35, it had passed over Queens, Brooklyn, Sandy Hook, Raritan Bay, Staten Island, Arthur Kill, and into New Jersey.

All three flights made radical changes in direction when they encountered sea breezes. Flights 22 and 24 changed from drifts to the south and southeast, respectively, to essentially parallel northeasterly courses, whereas Flight 21 turned from a generally southerly course to a westerly, then northerly, direction. It is apparent that if trajectories of contaminants are analogous to the trajectories of tetroons, which is a reasonable assumption, pollutants emitted from a diverse set of points in the metropolitan area on the morning of June 12, 1965, likely would have been thoroughly intermingled by noon. By afternoon, it would have been most difficult to identify the place of emission of pollutants collected in either state.

Evidence of interstate transport of gaseous air contaminants also was obtained in June 1966. Using an SO_2 detector built especially for aerial sampling, Sign-X Laboratories, Inc., Essex, Connecticut, under contract to the Public Health Service, flew a series of SO_2 sampling traverses along Arthur Kill and the Hudson River. Arthur Kill forms the boundary between New Jersey and New York in the Staten Island vicinity and the Hudson River separates Manhattan from New Jersey. While the helicopter was collecting SO_2 samples along the state borders, aerial photographs were taken of the portion of the boundary being sampled. The photographs, also by Sign-X Laboratories, Inc., were taken from a fixed-wing aircraft circling at an end of the traverse and well above the level at which the helicopter was operated.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40°15'
1754
1454
1700
FLIGHT 32 1202 EST JUNE 17, 1965
FLIGHT 7 1420 EST JUNE 8, 1965
FLIGHT 31 1406 EST JUNE 16, 1965
N

Figure 34. Tracks of tetroons flown June 8, 16, 17, 1965, at an altitude of approximately 500 feet.

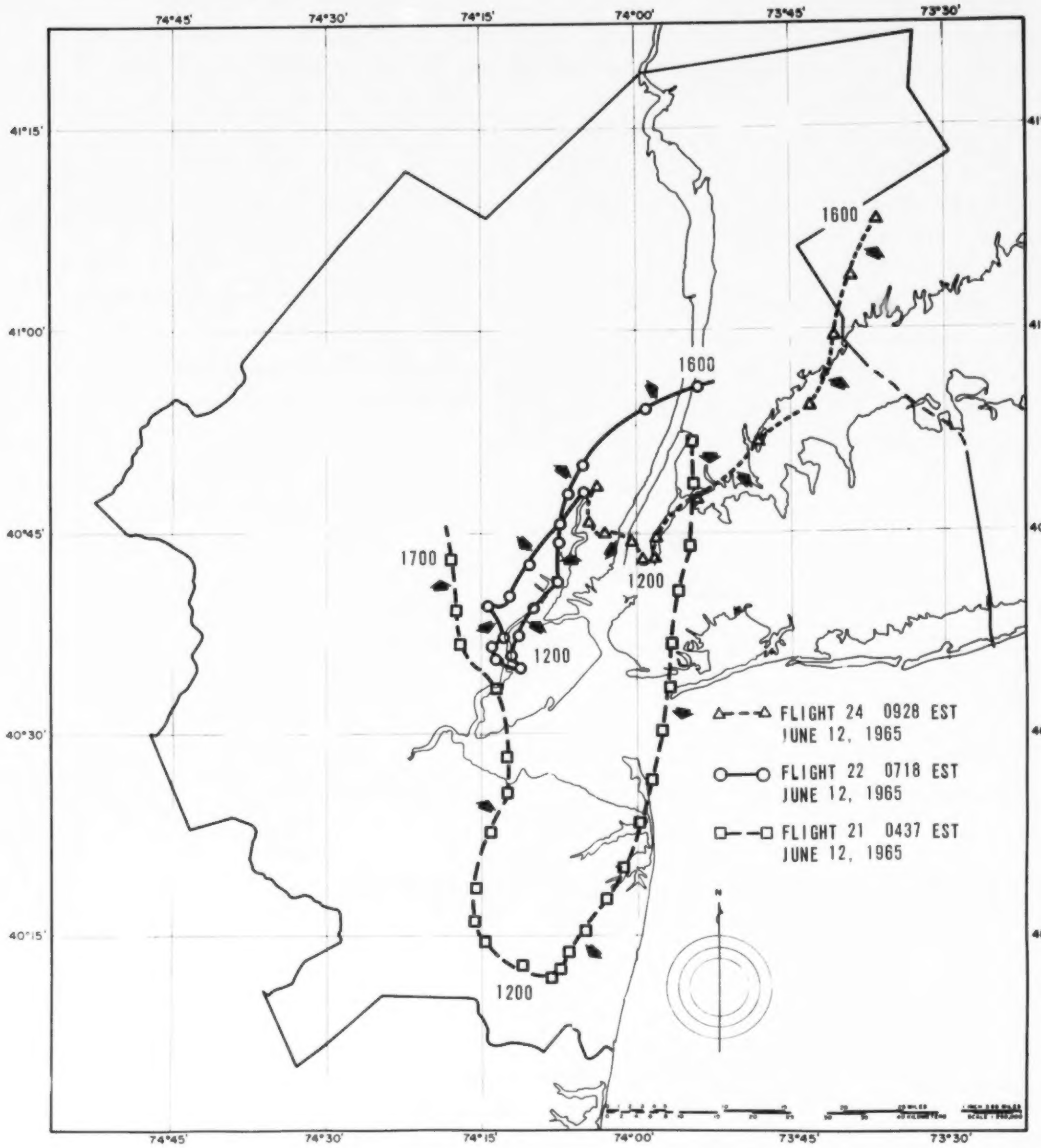

74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
41°15'
41°00'
40°45'
40°30'
40°15'
1600
1600
1700
1200
1200
1200
FLIGHT 24 0928 EST
JUNE 12, 1965
FLIGHT 22 0718 EST
JUNE 12, 1965
FLIGHT 21 0437 EST
JUNE 12, 1965
N

Figure 35. Tracks of tetroons flown June 12, 1965, at an altitude of approximately 500 feet.

On June 15, 1966, the sampling traverses revealed sizeable concentrations of SO_2 along the border and variations of SO_2 concentration of more than a factor of two as the helicopter passed through SO_2-laden plumes. Nine distinct plumes could be seen crossing Arthur Kill from west to east in a photograph taken at 0605 EST, June 15, 1966. Winds at 500 feet over Staten Island were observed to be from the southwest about 10 miles per hour at the time. Figure 36 shows the variation of SO_2 along a portion of Arthur Kill at near 500-feet elevation.

Sampling flights over the west-side docks of Manhattan Island at about the same time also showed marked variations of SO_2 concentrations with distance (Figure 37). Photographs taken along the Hudson River while the sampling flights were in progress also revealed visible plumes crossing from New Jersey to New York.

Winds at 1,000 feet were observed to be from the northeast on June 22, 1966. Using precisely the same methods as on June 15, Sign-X Laboratories, Inc., obtained photographic evidence of plumes crossing from New York to New Jersey. Simultaneously, easily measurable concentrations of SO_2 over both the Hudson River adjacent to Manhattan Island and Arthur Kill to the west of Staten Island were detected moving from New York to New Jersey.

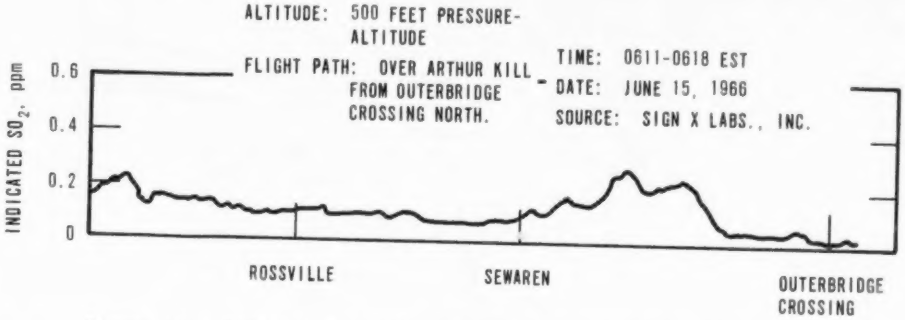


Figure 36. Replica of portion of recorder trace from airborne SO_2 sampler, 0611-0615 EST, June 15, 1966.

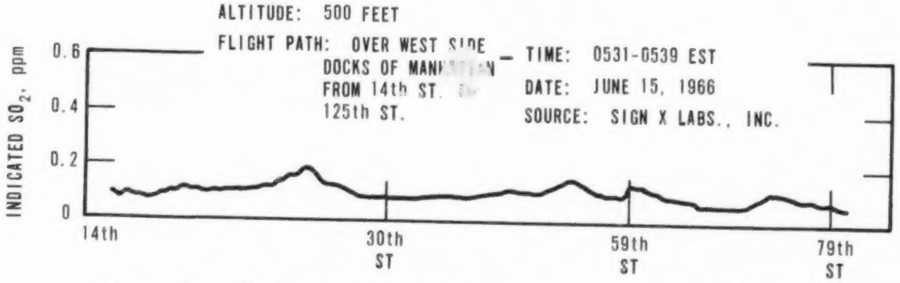


Figure 37. Replica of portion of recorder trace from airborne SO_2 sampler 500 feet above Hudson River 0534-0538 EST, June 15, 1966.

SECTION VI—EVALUATION AND CORRELATION OF RESULTS

QUANTITATIVE MEASUREMENT OF INTERSTATE TRANSPORT OF SO_2

During the sampling period, attempts were made to measure quantitatively the amounts of SO_2 crossing state borders by sampling the air quality above ground-level. Sign-X Laboratories, Inc., of Essex, Connecticut, using equipment installed in a helicopter to measure temperature, wet-bulb depression, pressure-altitude and sulfur dioxide, collected data on these parameters from the surface to as high as 3,000 feet. All sampling was within the New York - New Jersey metropolitan study area. At the same time, observations of wind speed and direction in the lower few thousand feet were made by New York University and Public Health Service personnel at sites in the Bronx and Staten Island, respectively. These data supplemented upper wind data collected by the U.S. Weather Bureau at J.F. Kennedy International Airport.

Flight patterns were developed and sampling days were selected to enhance the chance of gathering information that would demonstrate the interstate transport of SO_2. Flying was done on June 15, 16, 21, and 22, 1966.

Fifty-four vertical soundings were made. Data were collected on the vertical distribution of temperature (and consequently the vertical stability of the atmosphere) and SO_2 concentrations, and their changes in space and time. A series of quasi-constant-level traverses also were flown to provide data on the horizontal distribution of SO_2 at various altitudes.

On June 15 the low-level wind flow was from the southwest, parallel to the centerline of the sampling network. It was a warm summer morning, and no space heating was required. A low-level inversion developed in the outer suburbs (Figure 38). In the city itself, inversions sufficiently strong to trap SO_2 occurred at 70, 130, and 310 meters above the ground. Another occurred around 500 meters. There was some spatial variation in the height of the lower inversions, which were slightly lower near the upper Manhattan area than in the Arthur Kill - Staten Island area. The significant point, however, is that most of the SO_2 emissions were very effectively trapped by the low inversion. As seen in Figure 39, the indicated concentration of SO_2 decreases by a factor of 10 or more above the inversion in the vicinity of the major industrial areas.

Data from the traverses were reconstructed to develop a cross-section (a planar slice through the atmosphere) of the vertical distribution of SO_2 along Arthur Kill between Goethals Bridge and Outerbridge Crossing and below the inversion (Figure 40). The mean concentration of SO_2 in samples taken by the helicopter between 0600 and 0800 EST was 0.15 ppm. At the time, the wind observed in the lower 270 meters (about 900 feet), the height of the inversion, at

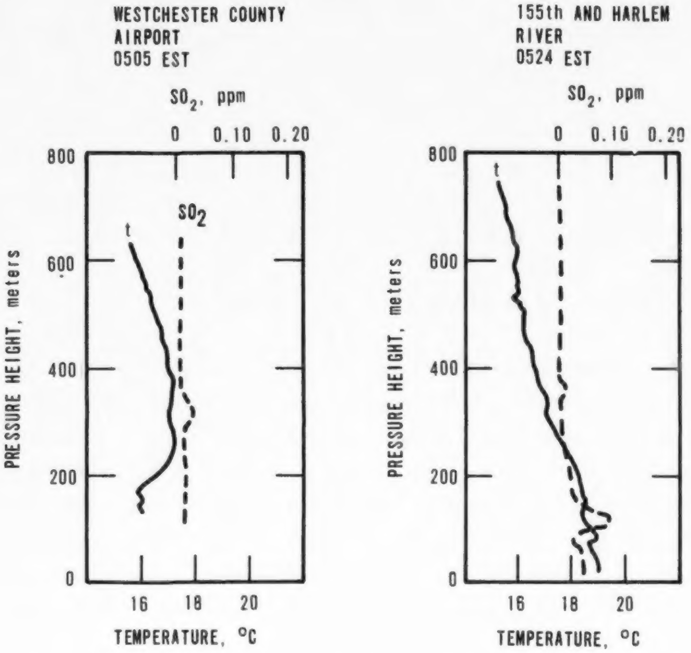


Figure 38. Temperature and sulfur dioxide vs pressure height June 15, 1966 (from Sign X Labs., Inc.).

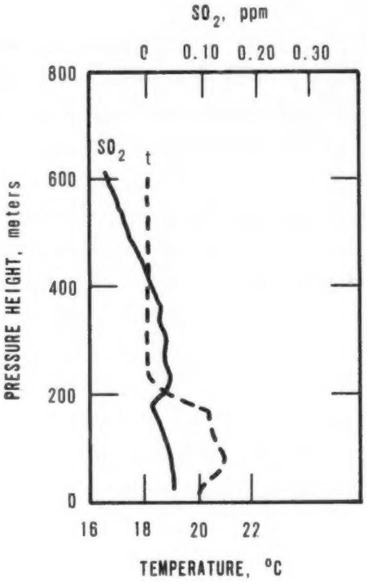
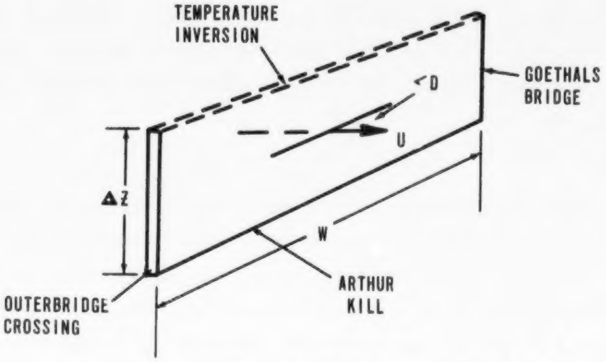


Figure 39. Temperature and sulfur dioxide vs pressure height at Outerbridge Crossing at 0728 EST, June 15, 1966 (from Sign X Labs., Inc.).



W	WIDTH OF CROSS SECTION (meters)
ΔZ	HEIGHT OF CROSS SECTION (meters)
$\bar{U}$	WIND SPEED (meters per second)
<D	ANGLE BETWEEN ORIENTATION OF CROSS SECTION AND WIND DIRECTION (degrees)

Figure 40. Schematic cross section of method for computing mass transport--example for Arthur Kill.

nearby Willowbrook Hospital averaged 230 degrees in direction and 4.1 meters per second in speed (about 8 mph).

The distance from Outerbridge Crossing to Goethals Bridge is 13.3 kilometers. The orientation of a line connecting the centers of the spans is 20° east of north. Based on the assumption that the average height of the trapping inversion between these hours was 270 meters and that most of the SO_2 in the vicinity was below the inversion, the quantity of air carrying the bulk of the SO_2 across Arthur Kill was calculated to be 7.35×10^7 m^3sec^{-1}. Each cubic meter contained an average of 405 micrograms of SO_2.

Based on these data, 2,980 grams of SO_2 per second were being transported from New Jersey to New York air space over Arthur Kill. This is about 12 tons per hour.

To ascertain whether these estimates were reasonable, the estimated emissions were determined for all study area zones located between two parallel lines with bearings of 230 degrees through Goethals Bridge and Outerbridge Crossing and upwind of the Arthur Kill. SO_2 emission rates for a minimum heating day totaled 26.4 tons per hour. Therefore, about half of the estimated emissions southwest of Arthur Kill crossed the New York - New Jersey boundary in the vicinity of Staten Island.

Another cross section was developed in the same manner for the west shore of Manhattan. Traverses were made from Pier 3 to 155th Street, a distance of 16.1 kilometers. At the time the traverses were made, the lower inversions were reasonably well eliminated, but a barrier for the SO_2 was created by the inversion at 500 meters. The wind direction, extracted from a streamline analysis of the winds over the metropolitan area, was 235 degrees, and the mean wind speed was 4 meters per second. The average concentration of SO_2 between the ground and

500 meters along the west side was 0.14 ppm, or 378 micrograms per cubic meter. Based on these observations, 6,970 grams of SO_2 per second, or 27.8 tons per hour, were being advected over Manhattan from the west between Pier 3 and 155th Street. The SO_2 emissions from appropriate upwind zones were found to be 32.1 tons per hour.

Similarly, a traverse along the East River between Williamsburg Bridge and 145th Street showed that 44.6 tons of SO_2 per hour were crossing the East River. Manhattan emissions, estimated from the emission inventory to be 17.1 tons per hour when added to the 32.1 tons per hour emitted upwind of the Hudson River, totaled 49.2 tons per hour. Thus, measured amounts of SO_2 crossing the East River and the estimated upwind emissions (44.6 and 49.2 tons per hour, respectively) agreed within 10 percent.

But not all SO_2 travels from west to east. On June 22, 1966, a series of traverses and soundings were made during a period (0800 to 0900 EST) when winds were northeasterly. By use of the same procedures applied to the June 15 data, 18,900 gms of SO_2 per second, or 75.6 tons per hour, were calculated to have traveled from the west side of Manhattan toward New Jersey. The aggregate of the upstream emissions, obtained by summing emissions from zones to the northeast in the 58 degree observed wind direction, was 34.0 tons of SO_2 per hour. Although agreement between the estimated upwind emissions and the calculated amount of SO_2 crossing the boundary on June 22 was poorer than on June 15, 1966, it should be noted that the trapping inversion on June 22 was at an altitude twice as great as that of a week earlier. A 3-meter-per-second change in the estimated wind speed would halve the calculated volume of air crossing the state boundary. Differences between wind speeds observed in the lower 2,000 feet above Staten Island and the Bronx exceeded this value.

In summary, data collected on 2 days when pollution was below average showed that tens of tons of SO_2 can be carried across state lines in either direction in the New York-New Jersey metropolitan area, even in the summer season.

CONTRIBUTION OF INTERSTATE SOURCES TO CENTRAL PARK'S SO_2 CONCENTRATION

An attempt was made to show the relative amount of SO_2 contributed by each upwind emission zone to the observed air quality level at a receptor site. The mid-morning of June 15, 1966, was selected for the experiment solely because meteorological factors were well known and the weather situation remained reasonably constant for several hours. Measurements of atmospheric stability were available for the central portion of the study area; upper-wind data from Staten Island and surface-wind information from the sampling network stations indicated that the flow was consistently from the southwest; and the period chosen was too early in the day for the sea breeze to complicate flow patterns. Under these circumstances, it was reasonable to expect that pollutants were being transported across state boundaries.

Diffusion calculations were made for the Central Park sampling station, which was downwind from many New York and New Jersey emission zones with sizeable annual outputs of SO_2.

A centerline was drawn upwind from Central Park to the boundary of the study area. The 78 emission zones that were within 9 miles of the centerline were suspected of contributing to the SO_2 concentration at Central Park.

The rate of SO_2 emission on a minimum heating day in each zone was extracted from the emission inventory and converted to a source strength in grams of SO_2 per second; it was assumed the SO_2 for each zone was being emitted at an effective height of 30 meters from a point source at the geometrical center of the zone. Seven power plants were considered separately, since they are relatively large sources, their positions are known precisely, and their effluents are emitted at elevations considerably higher than 30 meters. The source strength of each power plant was converted from tons of SO_2 per year, the units used in the emission inventory, to grams per second for the computations. No correction was made for the annual, monthly, or daily variation in power generation or the attendant SO_2 emission rates.

The Gaussian plume model for point sources was applied to the source strengths computed for each emission zone and power plant. Calculated concentrations yielded by this model are applicable for intervals of 3 to 15 minutes. The sum of individual contributions is 0.53 ppm.

The calculation is based upon average wind direction relative to source and receptor locations. Although wind direction varies about its mean, an average direction can be assigned for any desired time interval. Variation in direction increases with increasing time interval, however, so the fraction of time that wind actually is from the mean direction is less for long intervals of time than for short intervals. Correction factors can be applied to concentrations calculated for short intervals (e.g., 3 to 15 minutes) for which the wind is from a specific direction to indicate concentrations for longer intervals with the same nominal wind direction.[50/] A correction factor of 0.7 was used to convert the concentration value calculated for a 3-minute to 15-minute interval to that for a 1-hour interval at the same mean wind direction; 0.37 ppm was obtained. Observed concentrations at Central Park from 0600 through 1200 one June 15 are listed in Table XXXIII.

TABLE XXXIII

HOURLY SO_2 CONCENTRATIONS AT CENTRAL PARK ON THE MORNING OF JUNE 15, 1966

Hour (EST)	SO_2 Concentration, ppm
06	0.11
07	0.09
08	0.10
09	Missing
10	0.32
11	0.16
12	0.15

The calculated 1-hour results are in reasonable agreement with observed data for this type of computation. Of the computed 3-minute to 15-minute concentrations (0.53 ppm) for this particular receptor site, 0.08 ppm was attributed to New Jersey sources and 0.45 ppm to New York sources.

In summary, agreement between the calculated and measured concentrations lend credibility to the emission inventory and to the basic model applied. The results indicate that interstate pollution took place on June 15, 1966, and that about 15 percent of the sulfur dioxide detected in Central Park emanated from New Jersey.

CORRELATION OF POLLUTANT CONCENTRATIONS WITH WIND DIRECTIONS

To determine the influence of emission sources, both area and point types, on the various sampling sites in the "core" network, upper quartile pollution roses for SO_2 and CO were constructed for all reporting stations for which sufficient data were available. These were constructed by first tabulating the hourly average pollutant data by wind direction and then computing the percent of the total number of measurements for a given wind direction that represented the upper quartile as described in Appendix A.

If a large percentage of the pollutant values for a given wind direction occurs in the upper quartile, it is a good indication that a significant area or point source lies upwind in that direction. If these upper-quartile values are homogeneously distributed about the receptor site, it is a good indication that the sources also are uniformly distributed.

Table XXXIV presents the upper-quartile pollution-rose data for the months of June through August 1966, with a discussion of the significance for each station.

Figure 41 shows all 14 pollution roses in the 17-county area. Inspection of this figure in conjunction with those graphically depicting the emission inventory data further confirms the existence of numerous, large point and area sources distributed throughout both New York and New Jersey and fortifies evidence regarding the interstate nature of the SO_2 pollution problem.

Pollution roses for CO were constructed for seven stations for which sufficient data were available for the June through August 1966 period (Figure 42). With the notable exceptions of the Newark and Fairview sites, all stations reflected the expected homogeneous emissions of this automobile-exhaust pollutant. Both the Newark and Fairview stations showed the directional influence of adjacent traffic congestion at their respective locations.

The impact of the catalyst regenerators on the observed levels of CO at Willowbrook, Roselle, and Newark was minimal. In Manhattan, it was completely negligible. Roselle is the station most susceptible to effluents from these sources; however, 10 ppm is the probable maximum CO concentration that would be detected.

Closer to the plants, near the New Jersey approach to Outerbridge Crossing, concentrations as high as 60 to 80 ppm may occur under conditions of neutral stability. Several samples were taken in the vicinity, but values approaching the computed theoretical ground-level concentration were not found.

TABLE XXXIV SO_2 POLLUTION ROSE SUMMATION FOR JUNE THROUGH AUGUST 1966[a]

Station	Station No.	SO_2 Concentrations in Upper Quartile,ppm	Discussion
Willowbrook	001	≥ 0.10	Moderate indicators of sources to NE and SW; SW arm reflects industrial and public utility sources along and on either side of Arthur Kill. NE arm represents both interstate and intrastate transport of area emissions from NJ and NY and the effects of the nearby hospital heating plant.
Roselle	002	≥ 0.05	Strong indications of sources NE through SSE. Shows influence of multiple area and point sources in NJ.
Fairview	003	≥ 0.09	Moderately strong indicators of sources E through SE to SW; E arm reflects impact of sources in NY and sources along the Hudson River in NJ. Influence from SW attributed to industrial and power sources in vicinity of Newark Bay. Nearby power plant to the NW had little effect during survey period.
Bayonne	006	≥ 0.12	Moderately strong sources indicated to N reflect impact of major sources along upper portion of Newark Bay; to S, sources along Arthur Kill. Strong indicators to northeasterly quadrant reflect local sources and interstate transport from NY.
Newark	007	≥ 0.11	Moderate to strong source influences from NE through SE indicate presence of multiple area and point sources as shown in emission inventory; both intrastate and interstate transport suggested.
New Rochelle	016	≥ 0.05	Very strong influences of sources S to W, mainly SSW indicated. Major impact from NY sources.
121 St. - Manhattan	014	≥ 0.13	Heavy concentration of local area and point emissions to SW and W demonstrated. However, does not reflect anticipated strong emissions, from nearby point sources to the E and large area sources to N.
Central Park	013	≥ 0.13	Sizeable source areas in all directions indicated by generally uniform distribution. The maximum to E points toward power plants along East River; maximum to SW toward power plants on Hudson and heavy source areas in NJ.
Einstein	008	≥ 0.18	Very strong arm to SW confirms presence of multiple point and area sources. Moderate indicators to N and S reflect nearby area emissions.
Prospect Park	009	≥ 0.09	Moderately strong indicators in all directions except S through SE confirm site in midst of multiple sources. Rare occurrence of high SO_2 from S and SE indicates relative cleanliness of sea breezes.
Jersey City	010	≥ 0.09	Indicators to SSW and NW reflect intrastate NJ sources. However, an even stronger arm to ENE indicates interstate transport from sources in NY.
JFK Airport	011	≥ 0.10	Marked indicators of sources to the W and NW graphically demonstrate location of major emission zones. Substantial indications of sources to S and SE result from power plants in those directions.
Passaic	029	≥ 0.12	Indications of impact from NE through S reflect to a major degree intrastate transport from sources in Newark Bay area and interstate transport from NY sources.
NYU, Bronx	012	≥ 0.11	Indications of strong impact of multiple sources in all directions except W through NW. Impact of nearby power plant to WNW slight during sampling period.

[a] Note: The individual plots of these pollution roses appear in Appendix E.

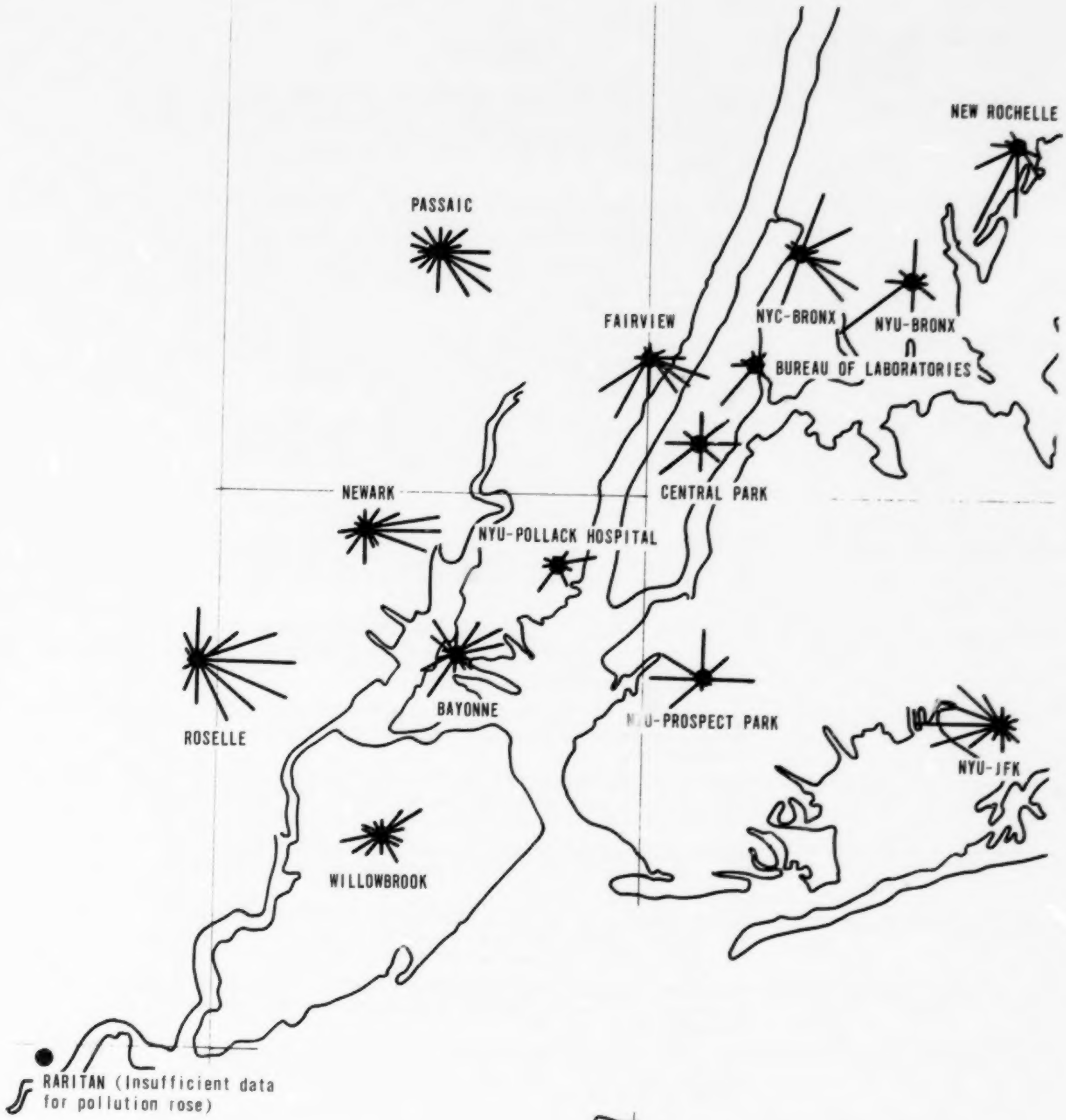

NEW ROCHELLE
PASSAIC
FAIRVIEW
NYC-BRONX
NYU-BRONX
BUREAU OF LABORATORIES
CENTRAL PARK
NEWARK
NYU-POLLACK HOSPITAL
ROSELLE
BAYONNE
NYU-PROSPECT PARK
NYU-JFK
WILLOWBROOK
RARITAN (Insufficient data for pollution rose)

Figure 41. Sulfur dioxide upper quartile pollution roses.

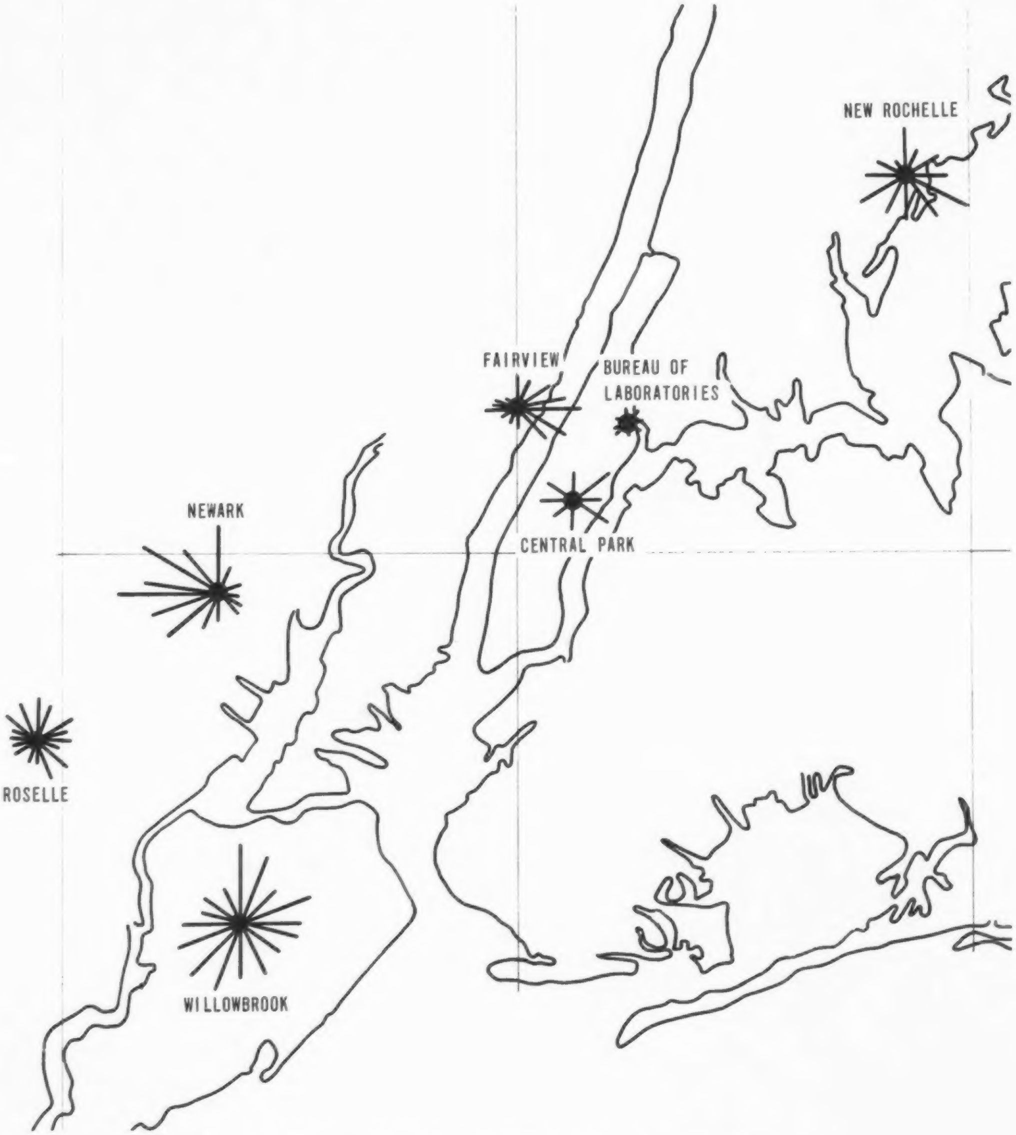

NEW ROCHELLE
FAIRVIEW
BUREAU OF LABORATORIES
NEWARK
CENTRAL PARK
ROSELLE
WILLOWBROOK

Figure 42. Carbon monoxide upper quartile pollution roses.

SECTION VII—DISCUSSION

CARBON MONOXIDE

Carbon monoxide concentrations recorded at sampling sites in the study area during the summer 1966 investigation did not exceed the tentative New York air quality objectives for this pollutant.

The State's tentative objectives are:

15 ppm	8-hour average CO concentration to be less than this value 85 percent of the time on an annual basis.
30 ppm	8-hour average CO concentration to be less than this value 100 percent of the time.
60 ppm	1-hour average CO concentration to be less than this value 99 percent of the time on an annual basis.

In-traffic samples obtained in New York City in 1966 approached the 99th percentile value of 60 ppm during hours of heavy traffic in one season of the year. From these data, it is probable that in-traffic concentrations or concentrations at locations adjacent to heavy traffic exceed the tentative New York objectives of a 60 ppm average concentration for 1-hour intervals or the 85th percentile value of 15 ppm for 8-hour intervals.

Regulations adopted pursuant to the Clean Air Act set limits on emissions of CO and hydrocarbons from all 1968-model (and later) automobiles sold in this country. Maximum allowable concentrations of exhaust pollutants are as follows:

Engine Displacement, in.^{3}	Hydrocarbons, ppm by volume	Carbon Monoxide, % by volume
50 - 100	410	2.3
100 - 140	350	2.0
>140	275	1.5

It is anticipated that more stringent limits for both CO and hydrocarbons, and perhaps for other pollutants, may be required in the future.

Most domestic automobiles have engines of greater than 140 cubic inches displacement. Only small foreign cars and the smallest domestic compact automobiles have engines of less than 140 cubic inches displacement. For purposes of this discussion, it is assumed that the average CO concentration in tailpipe gases from all gasoline-powered vehicles will be reduced to 1.5 percent by the control devices. This will provide a 60 percent decrease

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in CO from the present average of 3.8 percent. For all cars so equipped, the resultant emission factor will be lowered to 1,160 pounds of CO per 1,000 gallons of gasoline.

The immediate installation of suitable exhaust controls on all automobiles in the survey area would lower CO emissions from the current level of 5,296,000 tons to 2,230,000 tons per year. However, the control devices will be installed only on new cars, starting with 1968 models. Inasmuch as auto registration is expected to increase each year, an annual total of 2,230,000 tons represents a level that will never be reached unless allowable CO emissions are further reduced. With current exhaust control regulations, automobile emissions may approach about 4,250,000 tons of CO per year and then begin to rise again as the number of vehicles in use continues to increase.

Carbon monoxide emissions from gasoline engine vehicles have been projected through 1975. It is assumed that new cars will make up 9.3 percent of the 1968 motor vehicle total and that this same percentage of new cars will be purchased in each year through 1975. It is also assumed that 6.7 percent of the motor vehicles will be scrapped in 1968 and that the same proportion will be scrapped each year thereafter. These projections are based on nationwide averages for 1964 and current Federal regulations. Table XXXV and Figure 43 show that the resultant area total of CO emissions will be 4,888,000 tons per year in 1970 and 4,450,000 tons per year in 1975. Emissions will continue to decrease as pre-1968 vehicles are retired until about 1980 at which time CO concentrations will again start to rise as a result of increased motor-vehicle population.

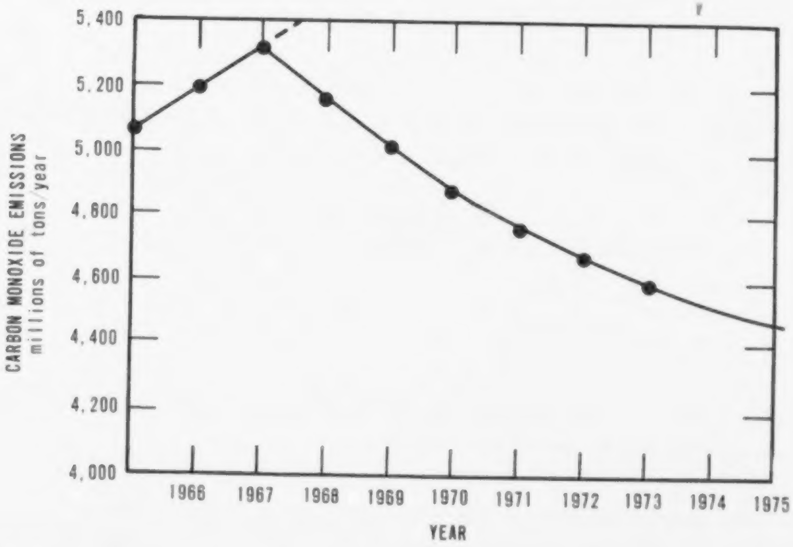

Figure 43. Effect of 1968 Federal standards on emissions of carbon monoxide from gasoline-powered vehicles.

Nonvehicular sources account for about 3 percent of the total emissions of CO in the study area. The major industrial sources are catalyst regenerating units at two petroleum refineries. Effluent from these units has fuel value; waste heat boilers should be installed to burn the large quantities of CO now being discharged from these two sources.

SULFUR DIOXIDE

The results of this investigations and of earlier studies and surveys of air pollution show that the levels of SO_2 in the New York - New Jersey metropolitan area are excessive and that the problem is interstate in nature. Pollutants generated throughout the bi-state area are emitted into a common air mass and are diffused and transported throughout the area without regard to state boundaries. The problem involves two related considerations; first, the quality of air necessary to protect the health and welfare of any persons in the area, and second, the means for achieving this quality.

TABLE XXXV

PROJECTED CARBON MONOXIDE EMISSIONS FROM GASOLINE-POWERED VEHICLES IN THE STUDY AREA 1965 THROUGH 1975

Year	Carbon Monoxide, tons/year From Cars Without Control Devices	From Cars With Control Devices	Total
1965	5,062,000	- - -	5,062,000
1966	5,186,000	- - -	5,186,000
1967	5,321,000	- - -	5,321,000
1968	4,960,000	198,000	5,158,000
1969	4,630,000	387,000	5,017,000
1970	4,320,000	568,000	4,888,000
1971	4,030,000	474,000	4,775,000
1972	3,760,000	912,000	4,672,000
1973	3,510,000	1,077,000	4,587,000
1974	3,280,000	1,237,000	4,517,000
1975	3,060,000	1,390,000	4,450,000

Criteria and standards for air quality are necessary as a basis for planning and implementing an air pollution abatement and prevention program. There is insufficient information to set ultimate air quality criteria and standards for all pollutants; definition of long-term genetic effects, for example, may require generations of study. In cases of gross pollution by well-studied pollutants such as SO_2, however, the requirements for improvement are clear enough that short-term objectives for abatement can be set.

Air quality criteria being developed by the U.S. Public Health Service for SO_2 in ambient air justify objectives no higher than the following:

0.10 ppm	24-hour average not to be exceeded more than 1 day in 100 consecutive days.

0.25 ppm	1-hour average not to be exceeded more than 1 hour in any 4-consecutive-day period.
0.50 ppm	5-minute average not to be exceeded more than 5 minutes in any 8-consecutive-~~day~~ hour period.

The ambient air quality objectives of the State of New York expected to be applicable to the City of New York follow:

0.1 ppm	24-hour-average SO_2 concentration to be less than this value 99 percent of the time on an annual basis.
0.25 ppm	1-hour-average SO_2 concentration to be less than this value 99 percent of the time on an annual basis.

These objectives are less restrictive than those being considered by the Public Health Service in that they would permit all of the 3 days or 87 hours of yearly excursion above the objective level to occur in a short period of time or even consecutively, whereas the Public Health Service objectives would require that any excursions be distributed throughout the year. In practice, however, it is expected that if the New York objectives are met, the excursions above the objective concentrations will be distributed in time and not occur consecutively. They may, however, occur more frequently during the seasons of heavy emissions than during those of lower emissions.

The Forward of the published New York Ambient Air Quality Objectives states: "These objectives are not intended to represent the ultimate in air quality achievement. It is anticipated that research and development will gradually make possible cleaner air at lower cost." This statement indicates recognition of the published levels as possible near-term objectives.

Air quality measurements demonstrate that SO_2 concentrations exceed the New York standard in all heavily populated localities of the project area. All sampling sites in this survey, even during the summer season, yielded concentrations of SO_2 exceeding 0.10 ppm more than 1 percent of the time. Summer-time levels at two sites did approach the standard; the 99th percentile value for Roselle was 0.11 ppm and that at New Rochelle was 0.13 ppm. With higher winter concentrations, however, the annual levels will, without doubt, exceed the New York standard even at these locations.

For only one sampling site utilized in this investigation is there a long-term accumulation of SO_2 data. This is the 121st Street Station of the New York City Department of Air Pollution Control, which is located in the midst of high-density SO_2 emissions from both point and area sources. It reflects its location by recording the highest ambient concentrations of SO_2.

Figure 44 is a frequency distribution of SO_2 data obtained at this Manhattan site for the period 1957 through 1965. This plot shows that daily SO_2 concentrations of 0.10 ppm were exceeded on about 70 percent of the days during that 9-year period and that 1 percent of the time the SO_2 values were greater than 0.55 ppm. Based on the assumption that a frequency distribution curve of the same slope would meet the New York State standard and that a linear relationship exists

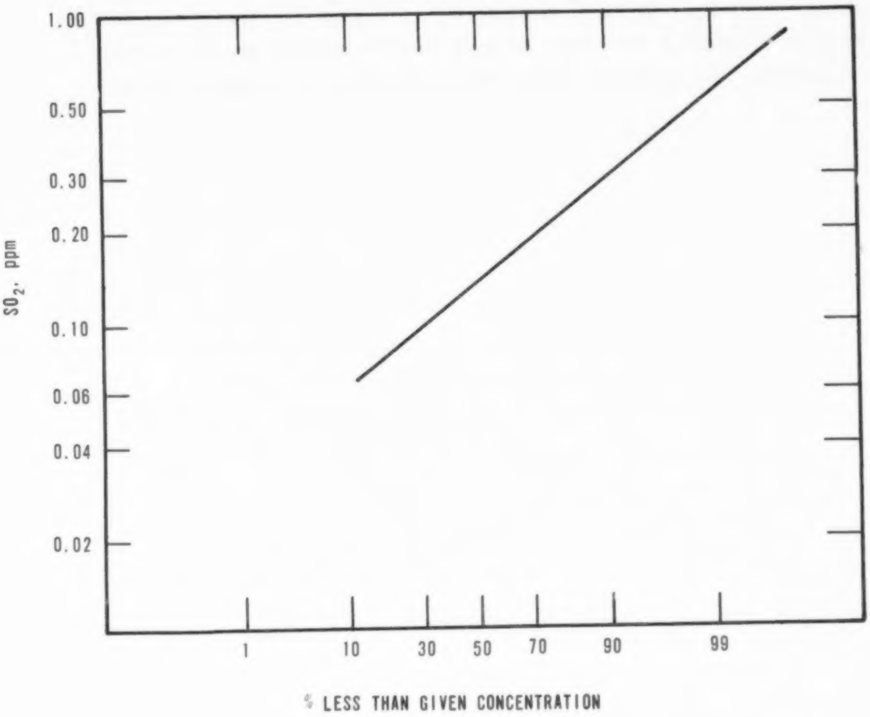

Figure 44. Frequency distribution of 24-hour sulfur dioxide samples for New York (121st St. Site) 1957 through 1965.

between emissions and air quality, it would be necessary to reduce contributing emissions by about 80 percent to reach a desirable ambient level.

Inasmuch as reduction of emissions must be based on the maximum rather than average or normal impact (in the New York - New Jersey area, Manhattan has the most serious SO_2 pollution), an across-the-board reduction to one-fifth the present level of emissions is demanded for the entire 17 county area, since all emitters contribute to the total pollution load.

An 80 percent reduction of SO_2 emissions from fuels now used in the 17-county area would require limiting the sulfur content of fuel oils to about 0.3 percent and that of coal to about 0.2 percent. These are not feasible levels at the present time; further, energy requirements and fuels used in the area will surely increase. Thus, the limiting of sulfur content of fuels as they are presently distributed and used is not, alone, sufficient to achieve air quality objectives.

Further, we recognize that this assumption of 80 percent across-the-board reduction in SO_2, while possibly sufficient to produce the desired air quality for the metropolitan area, is probably not practical. It does, however, indicate the magnitude of the job to be done. The exact level of reduction required in a receptor area depends on many variables, the most important of which is definition of the relative contribution to pollution by area sources and elevated point sources under the specific conditions imposed by terrain, meteorology, and physical location. In some locations, based on present conditions, a reduction of more than 80 percent may be required, whereas in many others, especially the outlying areas, this percentage is probably too high.

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APPENDIXES

Appendix A. Description of Project Design

Appendix B. Aerometry Operation and Techniques

Appendix C. Emissions Inventory Procedure

Appendix D. Summary of Atmospheric Emission Tests

Appendix E. Tables and Figures

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Appendix A

DESCRIPTION OF PROJECT DESIGN

AIR QUALITY NETWORK

SCOPE

The objectives of the air quality investigation were:

1. To determine the sources, intensities, and transportation between the States of New Jersey and New York of sulfur compounds, carbon monoxide, and particulate air pollutants from fossil-fuel combustion originating in the 17-county New York-New Jersey metropolitan area.[A1/]
2. To assess the danger to health and welfare of such air pollution in the two States.[A1/]

CRITERIA FOR THE NETWORK DESIGN

Three factors were basic in determining the criteria for the network design.

1. Conference date. A general date for the conference; namely, Fall 1966, required that the network design be pointed toward summertime weather conditions. There would be little opportunity to process and analyze data collected after September 1966.
2. Availability of samplers. The first pieces of Public Health Service air quality sampling equipment would not be available before April 1, 1966, and the last of the equipment would be ready in June 1966.
3. Established sampling sites. The State of New Jersey had already selected sites for three of their four integrated sampling trailers.

From these factors, the following important and controlling considerations evolved:

1. The design should be consistent with existing sampling sites, including those already selected for New Jersey's mobile equipment.
2. A network should be designed primarily to sense utility, industrial, and commercial emissions. Because only summer data would be collected, emissions from space heating would be minimum; other emissions would dominate.
3. The basic network should be oriented with the most prevalent wind directions during the summer. Such orientation would increase the efficiency with which the sampling equipment could be used. Samplers should be placed to represent areas of habitation or occupation; some should be downwind of the major source areas a high percentage of the time; others should be placed to observe the lateral spread of contaminants; and still others to note background contamination levels.

METEOROLOGICAL FACTORS

Meteorological factors, specifically summertime prevailing wind directions, were the primary considerations in selecting the orientation of the network. There are four U.S. Weather Bureau

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stations within the study area and there are many other places in the area where wind data are collected regularly. The U.S. Weather Bureau Stations are: Newark Airport, LaGuardia Airport, J.F. Kennedy International Airport, and Central Park. Wind data collected at the three airports during the 10-year period 1951 through 1960 showed that wind directions were within 22-1/2 degrees of a southwest-northeast line at Newark 48 percent of the time during June, July, and August. The axis with the next highest frequency was north-south with 39 percent. At LaGuardia, the summertime wind direction occurs on the southwest-northeast and north-south axes with the same frequency, 43 percent. At J.F. Kennedy International Airport winds along the north-south axis are most prevalent. Wind directions occur along this axis 52 percent of the time, and along the northeast-southwest axis 41 percent of the time (Table A-I).

TABLE A-I
PERCENTAGE FREQUENCY OF WIND DIRECTION BY OCTANTS
FOR JUNE, JULY, AND AUGUST[a,b]

Direction	LaGuardia Airport	J.F. Kennedy Airport	Newark Airport
N	14	17	15
NE	20	13	17
E	8	9	11
SE	16	15	14
S	29	35	24
SW	23	28	31
W	18	14	20
NW	19	14	17

[a] Source: Table B. Decennial Census of U.S. Climate, Summary of Hourly Observations, 1951-1960 for LaGuardia, Kennedy and Newark Airports, U.S. Weather Bureau, Washington, D.C.

[b] Figures are frequency of occurrence of winds of within 22-1/2 degrees of direction indicated. For example, the percentage frequency indicated for N is the mean frequency for NNW, N, NNE; and for NE, the mean frequency for NNE, NE, ENE. Since eight points of the compass are considered twice, the sum of the frequencies exceeds 100 percent.

Southerly winds occur at J.F. Kennedy International Airport somewhat more often than at LaGuardia and Newark Airports. This reflects the sea breezes that occur frequently at J.F. Kennedy International Airport during the summer. The sea breeze effect was considered primarily a local phenomenon. For the metropolitan area as a whole, air flow is believed to be along the southwest-northeast axis most frequently. If wind direction is reasonably normal during a summer season the flow should be within 22-1/2 degrees of the southwest-northeast axis over one-third of the time. Therefore, the major axis of the network was oriented along the southwest-northeast axis.

SOURCE AREAS

After the axis of the network was oriented, the positioning of the axis was determined. In summer, the major fossil-fuel-derived pollution sources are industrial and power generation establishments. The truly large establishments, including power plants, are concentrated in

New Jersey along and to the west of Newark Bay and Arthur Kill. In New York, the heaviest concentration is along the East River extending through the Hell Gate into south Bronx.

An axis oriented northwest-southeast could be roughly fitted through both of these industrial concentrations.

DATA FROM OTHER AGENCIES

The preliminary protocol[A1/] contained a list of potentially available air quality monitoring equipment operated by various agencies. The locations of the equipment were ascertained and plotted on a map of the New York-New Jersey metropolitan area. A line oriented 45 degrees east of north (SW-NE) through New York City's Central Park monitoring station also passes through the City's 121st Street station and New Jersey's mobile monitoring station location in Bayonne. The axis was therefore most conveniently positioned through the Central Park station. Quasi-control sites were tentatively located near Greenwich, Connecticut, and near New Brunswick, New Jersey, on the network axis. Air quality data from these locations would indicate background contamination levels near the periphery of the study area. Subsequently, New Rochelle, New York, was substituted for Greenwich to make use of an already established monitoring station operated by the New Rochelle Department of Public Health, and the Raritan Arsenal was substituted for New Brunswick to make use of the Abatement Branch's chemical laboratory and equipment for air quality monitoring.

Thus, a basic axis oriented within a few degrees of the direction of the prevailing summertime air flow was established.

To fit the remaining monitoring stations into a logical pattern, minor axes were constructed perpendicular to the basic axis. Where possible, pairs of monitoring stations were located on these minor axes so that they were equidistant from the basic axes.

Arrangements were made to obtain SO_2 data collected by the Geophysical Sciences Laboratory, New York University, in conjunction with their urban dynamics research. Two of their monitoring stations, at Margaret Hogue Hospital in Jersey City and at Albert Einstein Hospital in the Bronx, were found to be located within a few hundred yards of the basic axis. Two others, at J.F. Kennedy International Airport and at the Department of Health, Passaic, New Jersey, lay on a line through the Central Park station drawn perpendicular to the basic axis. The fifth station, in Prospect Park, Brooklyn, was in the midst of a densely populated area west and south of the most heavily industrialized portion of Brooklyn.

PUBLIC HEALTH SERVICE SITES

It was now possible to select logically general areas for air monitoring stations to be operated by the Field Investigations Section, Abatement Branch. The Field Investigations Section had primary control in the selection of these major sampling sites. Criteria for selection of the sites were as follows.

1. The site must be compatible with the "core network" distribution of sampling stations.
2. The site must represent as large an area as possible. It should not be adjacent to a

major pollution source, but it should be in a moderately to heavily populated or travelled area.

3. The site must be located so that nearby obstructions are minimal. If obstructions are present, the distance between the site and the obstructions should be at least 2.5 times the difference in height between the intake manifold and the height of the nearest obstruction. If obstructions are unavoidable, the nearest obstructions should be to the east of the site.
4. The site should be reasonably convenient to commercial 215 to 230-volt, 100-ampere power.
5. The site should be located so that it is not obviously vulnerable to vandalism or so that precautions against vandalism can be taken.
6. The site should be reasonably convenient to Raritan Arsenal to minimize travel time to and from the Arsenal, the home office of maintenance personnel.
7. The site should be owned or controlled by persons or agencies sympathetic to the objectives of the project to avoid undue complications in negotiating for access to the site.

A number of potential sites satisfied the criteria. Because the Field Investigations Section had sampled for SO_2 at Willowbrook Hospital or Staten Island, one such site, during the summer of 1965, one of the mobile stations was located there. Another site was located approximately on a line through Willowbrook and perpendicular to the basic axis so that it would be northwest of the axis and about the same distance from the axis as Willowbrook. This site would be in the area of Elizabeth and Roselle, New Jersey. Arrangements were made with city officials of Roselle, New Jersey, to install the station in the parking lot of the Roselle Station of the New Jersey Central Railroad. The third mobile facility was located on the Palisades on a line passing approximately through the J.F. Kennedy International Airport, Central Park, and Passaic sampling stations. This location was on the ridge between the New Jersey Meadows and the Hudson River in Fairview, New Jersey. Because no air pollution data on an area in Brooklyn were available, the Field Investigations Section installed an SO_2 sequential sampler at Ft. Hamilton near the Brooklyn approach to the Verrazano-Narrows Bridge.

THE FINAL NETWORK

These 13 sites made up the "core network" (Figure A-1) where sequential or continuous samples of SO_2 were collected for the project. In addition, New Jersey had planned to establish a control station near Ancora, inland from Atlantic City and about 85 miles southwest of the center of the core network, to provide data on background levels of contamination; however, the site was not placed on line in time for the summer sampling period.

The core network was designed to gather data on sulfur compounds, primarily SO_2; however CO was also sampled at the 121st Street Laboratory, Newark, Bayonne, Willowbrook, Roselle, Fairview, and Ancora. The Roselle and Fairview sites for Public Health Service Mobile Air Sampling Station (MASS) units were purposely stationed near areas of heavy automobile traffic to detect street-side and presumably relatively large CO concentrations as well as ambient concentrations for the general area, depending on wind direction.

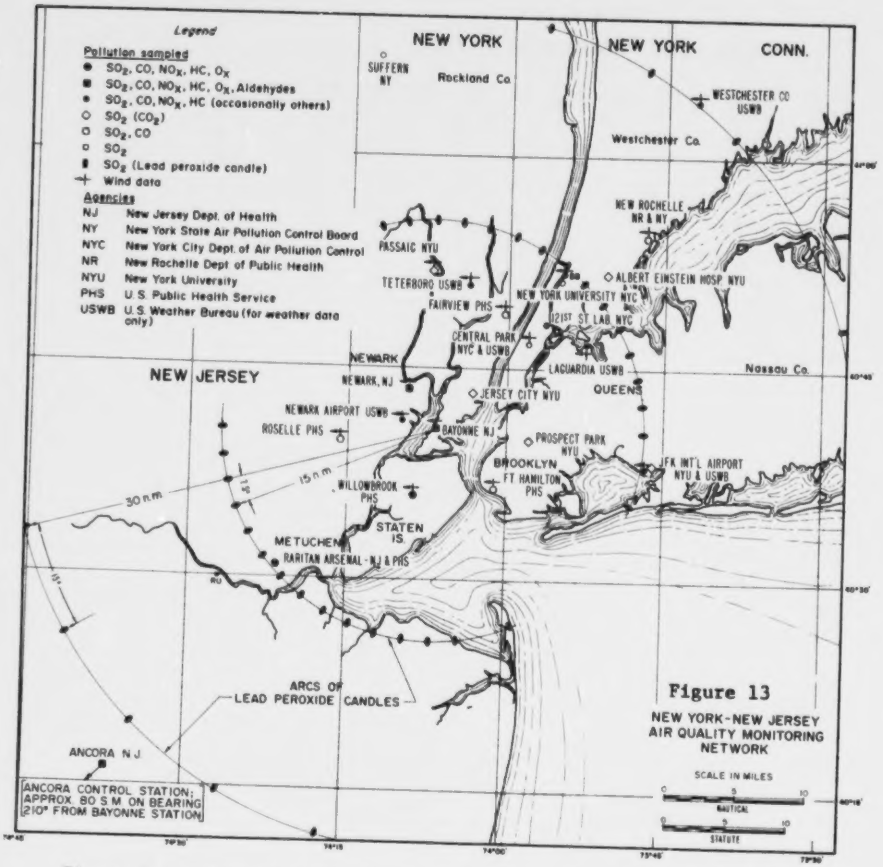
Legend
Pollution sampled
● SO2, CO, NOx, HC, Ox
■ SO2, CO, NOx, HC, Ox, Aldehydes
• SO2, CO, NOx, HC (occasionally others)
○ SO2 (CO2)
□ SO2, CO
▫ SO2
▮ SO2 (Lead peroxide candle)
Wind data
Agencies
NJ New Jersey Dept. of Health
NY New York State Air Pollution Control Board
NYC New York City Dept. of Air Pollution Control
NR New Rochelle Dept of Public Health
NYU New York University
PHS U.S. Public Health Service
USWB U.S. Weather Bureau (for weather data only)
NEW YORK
SUFFERN NY
Rockland Co.
NEW YORK
CONN.
WESTCHESTER CO USWB
Westchester Co.
NEW ROCHELLE NR & NY
PASSAIC NYU
TETERBORO USWB
FAIRVIEW PHS
NEW YORK UNIVERSITY NYC
ALBERT EINSTEIN HOSP NYU
121ST ST LAB NYC
CENTRAL PARK NYC & USWB
NEWARK
NEWARK, NJ
LAGUARDIA USWB
QUEENS
Nassau Co.
NEW JERSEY
JERSEY CITY NYU
NEWARK AIRPORT USWB
ROSELLE PHS
BAYONNE NJ
PROSPECT PARK NYU
BROOKLYN
FT HAMILTON PHS
JFK INT'L AIRPORT NYU & USWB
15 n m
30 n m
WILLOWBROOK PHS
STATEN IS.
METUCHEN
RARITAN ARSENAL - NJ & PHS
ARCS OF LEAD PEROXIDE CANDLES
Figure 13
NEW YORK-NEW JERSEY AIR QUALITY MONITORING NETWORK
SCALE IN MILES
NAUTICAL
STATUTE
0
5
10
ANCORA N.J.
ANCORA CONTROL STATION; APPROX. 80 S.M. ON BEARING 210° FROM BAYONNE STATION

Figure A-1. New York-New Jersey Air Quality Monitoring System.

The core network was circumscribed by two concentric rings of lead peroxide sulfation candles. The rings were centered on the Bayonne site and had radii of 15 and 30 nautical miles. The candles were placed at 7.5- and 15-degree intervals in the inner and outer rings, respectively.

High-volume filter samplers for suspended particulate were installed at the four Public Health Service sampling sites and at the Laboratory at Raritan Arsenal. Particulate data were also acquired from the two New Jersey sites (Newark and Bayonne), the 121st Street Laboratory (NYC), and New Rochelle.

Additional sampling for hydrocarbons, oxidants, and other pollutants was performed at some of the sites. Table A-II is a list by station of all sampling at each site.

CONSIDERATIONS IN DESIGN OF THE EMISSIONS INVENTORY

The inventory of air pollution sources and emission strengths within a metropolitan airshed provides the basic groundwork upon which immediate and future air conservation activities can be established. The extent and scope of such a survey depends greatly on the particular study objectives plus

TABLE A-II

DATA ON AIR MONITORING STATIONS

Station Name	Code	Agency	SO_2	OX	NO_2	NO	CO	HC	MET	NHV	PbO_2	H_2S	AISI	LAB
Willowbrook	001	USPHS	X	X	X	X	X	X	X	X	X	X		
Roselle	002	USPHS	X				X		X	X	X	X		
Fairview	003	USPHS	X				X		X	X		X		
Fort Hamilton	004	USPHS	X[a]						X	X	X	X		
Raritan	005	USPHS	X				X			X	X			X
Bayonne	006	NJ State	X	X	X	X	X	X	X	X	X	X	X	
Newark	007	NJ State	X	X	X	X	X	X	X	X	X	X	X	
Einstein	008	NYU	X											
Prospect	009	NYU	X											
Jersey	010	NYU	X											
JFK	011	NYU	X											
Osborn	012	NYC	X										X	
Central Park	013	NYC	X				X	X	X		X	X	X	
121st St. Lab	014	NYC	X		X	X	X	X		X	X	X	X	
New Rochelle	016	NY State	X				X		X	X	X	X	X	
Newark Airport	017	NJ							X					
LaGuardia Airport	018	USWB							X					
Teterboro Airport	019	USWB							X					
Westchester County Airport	020	USWB							X					
Ancora[a]	021	NJ State	X	X	X	X	X	X	X					
Passaic	029	NYU	X											
Bronx	088	NYU							X					
JFK	089	USWB							X					

Legend:
SO_2 - sulfur dioxide
OX - oxidant
NO_2 - nitrogen dioxide
NO - nitric oxide
CO - carbon monoxide
HC - total hydrocarbons
MET - wind speed, direction
NHV - normal Hi-Vol
PbO_2 - lead peroxide candle
H_2S - hydrogen sulfide (silver plates)
LAB - laboratory facilities
AISI - soiling index

[a] Not on line in time to provide data during summer 1966.

the available resources. A comprehensive emission inventory, including point-source inspections, extensive questionnaires, and source testing, requires considerable time and manpower, however. To meet the demands of this particulate study, a modified rapid survey method was employed.[A2]

APPLICATIONS

The objective of this inventory is to locate and quantify emissions from industrial, governmental, commercial, and domestic sources for the following applications:

1. To provide evidence of the existence of source emissions within the study area and to define the location, magnitude, frequency, duration, and relative contribution of these emissions.
2. To demonstrate by use of mathematical diffusion models the impact of air pollutants on receptor areas under the variety of meteorological conditions prevalent during the changing climatic conditions of the year.
3. To provide, by correlating the diffusion estimates with actual data from the air quality monitoring network, evidence whether interstate transport of air pollutants can and does occur, and whether it is of sufficient intensity and duration to endanger the health and welfare of the population.

4. To provide background data needed to evaluate the effectiveness of future control programs.

TECHNIQUE

The technique utilized for this emissions inventory consists of the following general steps. (A more detailed description of the technique is included as Appendix C.)

1. Division of the survey area into emission zones, based on similarities in land use, population density, fuel use patterns, vehicular traffic patterns, or other definable homogeneities.
2. Accumulation of data on emission sources that are generally found to be broadly distributed within each zone. Included here are data for residential, institutional, and commercial space and water heating; private refuse incineration; and mobile (automotive) sources.
3. Accumulation of data on major point sources located at specific sites within each emission zone. Included here are data for major fuel users and industrial pollution sources.
4. Estimation of emissions of sulfur compounds and CO based on fuel composition and quantities, types of processes and equipment, and appropriate emission factors. Where control equipment is utilized, actual or average collection efficiencies corresponding to the type of equipment are employed.
5. Calculation of the zone emissions for a minimum, average, and maximum degree-day to demonstrate the contribution of area space heating and cooling demands to the total pollution load.

   For this survey, the nine counties of New Jersey were subdivided into 260 emission zones; the five counties of New York City into 222 emission zones; and the remaining three New York counties into 125 emission zones.

DATA TYPES AND SOURCES

The various types of data and the sources from which they were obtained are shown in Table A-III.

Emission factors utilized in the calculation of zone totals have been published by the state of New York[A3/] and the U.S. Public Health Service.[A4/]

METEOROLOGICAL DATA ACQUISITION

SURFACE NETWORK

The primary weather parameters of concern in air pollution studies are wind speed, wind direction, and atmospheric stability.

The design of the network for collecting air quality and meteorological data gave cognizance to the distribution of existing, well-maintained and calibrated wind observing stations operated by, or under procedures of the U.S. Weather Bureau. Four U.S. Weather Bureau stations are in the New York-New Jersey metropolitan area: Central Park, LaGuardia Field, Newark Airport, and J.F. Kennedy International Airport. Weather data are collected at Teterboro and Westchester County

TABLE A-III. EMISSION INVENTORY DATA - TYPES AND SOURCES

Source	Type	Category
1. US Bureau of Census -Census Tracts, Census of Housing- 2. Rand McNally Commercial Atlas & Marketing Guide 3. NY & NJ State Files and Records (nonconfidential) 4. Fortune Directory of Manufacturers	Zoning 1965 Population by Zone Zone Areas Point Source Location Total Fuel Use	Statistical Data for Emission Zones
1. US Bureau of Census Census of Housing 2. Minerals Yearbook, Fuels	Dwelling Units per Zone Fuel Type by Dwelling Domestic Incineration	Domestic Fuel & Refuse Data
1. Mailout Questionnaire 2. NY & NJ State Files and Records (nonconfidential)	Local Government & School Units Private Institutions Municipal Incineration	Governmental & Institutional Fuel & Refuse Data
1. Mailout Questionnaire 2. Plant Visit Questionnaire 3. "Fuels & Electrical Energy Consumed in Manufacturing Industries: 1962" 4. NY & NJ State Files and Records (nonconfidential)	Industrial Fuel - Process & Space Heating Industrial Process Industrial Incineration	Industrial Fuel, Process & Refuse Data
1. All Accumulated Data	Total Fuel Use Total Domestic, Governmental, & Industrial Fuel Use (Total Fuel - Total Domestic Government & Industrial Fuel - Commercial Fuel) Commercial Incineration	Commercial Fuel & Refuse Data
1. Tri-State Transportation Agency Records	Gasoline and Diesel Fuel Use Vehicle Registration Vehicle Miles	Transportation Data

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Airports by personnel other than U.S. Weather Bureau personnel, but U.S. Weather Bureau observation procedures are used.

Wind equipment at Newark and Hudson County Park, Bayonne, New Rochelle, and New York University was operated by local governments or by universities, and data were readily available to the Public Health Service staff.

The Public Health Service MASS units installed at Willowbrook Hospital, at Roselle, and at Fairview have wind sensors as an integral part of their equipment. A portable wind sensor, similar to the sensors installed in the MASS units, was placed at the Ft. Hamilton sampling station.

Table A-IV lists the type of wind sensing equipment at each station.

Data Reduction

To permit integration of the diverse wind data with air quality information, print-outs of hourly speed and direction data were obtained for each meteorological station. A monthly wind rose for each station was then prepared.

TABLE A-IV. WIND EQUIPMENT USED TO COLLECT DATA FOR NY-NJ AIR POLLUTION ABATEMENT ACTIVITY

Station No.	Location	Agency	Type of Wind Sensor	Date of Valid Data -NLT- 1966
001	Willowbrook, S.I., NY	PHS	MASS Unit - CLIMET W.S. Trans. 011-1 W.D. Trans. 012-7 Transiator - 012 - 11 Sigma Computer	June 18
002	Roselle Park, NJ	PHS		June 21 June 21
003	Fairview, NJ	PHS		June 23
004	Ft. Hamilton, Brooklyn, NY	PHS	CI-3 CLIMET W.S. Trans. 011-1 W.D. Trans. 012-1 Transmitter 013-1	June 16
006	Hudson Co. Park, Bayonne, NJ	NJ	RAIM	June 1
007	Neward, NJ	NJ	RAIM	June 1
013	Central Park, NY, NY	USWB	Triple Register[a]	May 1
016	New Rochelle, NY	New Rochelle Health Dept.	Aerovane	June 1
017	Newark Airport, NJ	USWB	F-420	June 1
018	La Guardia Airport, Queens, NY	USWB	Triple Register	June 1
019	Teterboro Airport, NJ	NYP of A	F-420	June 1
020	Westchester Co. Airport White Plains, NY	(Co. Airport Corp.)	Aerovane	June 1
088	Bliss Bldg., Bronx, NY	NYU	Aerovane	May 22
089	JFK Airport, Jamaica, NY	USWB	F-420 Series (Electric Indicator Co.)	June 1

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[a] Central Park has both F-420 and Robinson three-cup wind devices. The Robinson device drives triple register from which data are collected for "Daily and Hourly Weather Records for the Week."

A mean hourly wind speed and direction were desired from each station, but because of the manner in which the wind data were recorded, this goal was not obtainable at several of the stations. The following procedures were used to obtain or approximate hourly mean values at the various stations:

1. Public Health Service Data (Sta. #1, 2, 3, 4)

   All Publich Health Service installations have analogue recorders for both speed and direction. All recorder charts were manually reduced. The mean speed and mean direction were determined by use of the techniques described in Appendix B. Data were tabulated on SEC Form 1041, Abatement Branch Wind Data Record, for convenience in key punching and subsequent data processing.

2. New Jersey Data (Sta. #6, 7)

   The recorder record provides wind speed as an analogue trace and direction as an event record. New Jersey uses analogue-digital converter equipment to obtain and key-punch 30-minute mean data. The data were summarized in essentially the same format as were the Public Health Service data.

   The monthly summaries of 30-minute data were retabulated by Public Health Service personnel on SEC Form 1041. Data for the mean for the period 30 to 59 minutes past the hour were used as the hourly mean in the final summaries.

3. New Rochelle (Sta. #16)

   The analogue wind speed and direction data were reduced by New Rochelle personnel. The procedures used were identical to those used by the Public Health Service. The monthly listing of hourly values was transcribed by Public Health Service personnel onto SEC Form 1041.

4. Airport Data (Sta. #17, 19, 20, 89)

   Wind data for the stations at Newark, Teterboro, Westchester County Airports, and J.F. Kennedy International Airport were extracted from the official U.S. Weather Bureau surface observation form, WBAN 10. The wind speed and direction are observed at these stations primarily for use in operating aircraft.

   At least one, and often several, wind observations are recorded on the WBAN 10 each hour. The "record" observation, however, is always made and recorded in the last few minutes of each hour.[A5] Wind data from the record observation were extracted from the WBAN 10, transcribed to SEC Form 1041, and used as the hourly mean.

5. Central Park (Sta. #13)

   The U.S. Weather Bureau collects wind data at Central Park on a triple-register recorder. Wind direction is recorded as events at 1-minute intervals to eight points of the compass. Wind speed is recorded as miles of wind travel (analogous to an odometer on an automobile). The Weather Bureau Office, New York City, publishes hourly prevailing wind direction and mean wind speed for Central Park in "Daily and Hourly Weather Records for the Week."[A6] Data were transcribed from this publication to SEC Form 1041 for key punching and processing.

6. LaGuardia Airport (Sta. #18)

   LaGuardia Airport also has a triple register in addition to wind equipment used primarily to support aviation interests. The triple-register records were obtained from the U. S. Weather Bureau, LaGuardia Airport Station, and the hourly data were extracted from the record by Public Health Service personnel. Wind direction data are to eight points of the compass. Hourly mean speed is actually miles of wind travel for each hour.

7. New York University (Sta. #88)

   Wind speed and direction data are recorded on analogue charts at this station. Hourly data were extracted from the charts by Public Health Service personnel and recorded on SEC Form 1041.

Exposure of Wind Sensors

All airport equipment is exposed to obtain data for aircraft interests and is considered representative of surface conditions in unobstructed locations.

New Rochelle's sensor is mounted on a 13-foot mast on the roof of a three-story building. The building itself causes some eddies that are picked up by the sensor. Trees in the vicinity exceed the height of the sensors. Several buildings within two blocks are also higher. Generally, wind directions are reasonably representative, but wind speeds are lighter than at nearby sites without obstructions.

The wind sensor of the Central Park Station is located 62 feet above the ground on Belvedere Tower. Its exposure is excellent considering that it is in the midst of a tremendously densely populated urban area.

The wind equipment at Hudson County Park, Bayonne (Sta. #6), has an excellent exposure. The equipment is 30 feet above the ground. A grove of small Sycamore trees, the tops of which are about the same height as the wind sensors, is located to the south and southeast of the station. The nearest tree is about 80 feet away. Directions are very representative of the Newark Bay area. Wind speeds are expected to be slightly too low when directions are east, southeast, or south. Winds with westerly components have a fetch over Newark Bay and are stronger than might otherwise be expected.

Newark (Sta. #7) is in a parking lot opposite Pennsylvania Station. The sensor is on a 30-foot mast, but the station is located across the street from a building 50 or more feet high. Neither wind directions, or speed can be accepted as representative of the City of Newark without a careful study of several months of wind data. A major portion of the time, the sensor seems to react to small-scale eddies caused by the building.

The New York University (Sta. #88) wind equipment is located on about a 25-foot tower on the roof of a three-story classroom building, on the University Heights Campus, on a bluff overlooking the Harlem River. It is one of the higher spots in the Bronx, and the exposure is excellent.

Exposure of the MASS unit at Willowbrook Hospital was not particularly good; however, access to power sources could not be obtained at more favorable locations. The unit was located on the north side of a parking lot for one of the six-story hospital buildings. A grove of oaks about 30 feet tall extended from a bearing of 250 degrees through north to 110 degrees from the station. The nearest tree was about 40 to 50 feet away. The nearest building, the six-story structure mentioned before, was located 400 to 500 feet to the southeast. The stack of the hospital power plant was about 1,400 feet from the trailer on a bearing of 14 degrees.

The grove of trees was expected to reduce observed wind speeds drastically when winds had northerly components. Because of the obstructing building, observed directions were expected to be unrepresentative when the air flow was from the southeast. A 10-foot extension was added to the wind mast on Aug. 3, 1966, to lessen the influence of the nearby trees. Little, if any, change in the character of the wind data was noted, however.

The wind sensors at Ft. Hamilton were located about 40 feet above the ground. The 30-foot wind mast was mounted on the roof of a garage about 10 feet high. The Verrazano-Narrows Bridge was about a mile to the west. Several tall apartment buildings were about three-quarters of a mile to the east. All buildings within about a half a mile were one or two stories. Generally, the exposure was excellent compared to other in-city installations.

The MASS unit at Roselle was in the center of a small traffic circle on the south side of the Roselle railroad station. Other than a four-story building about 100 yards to the east, most structures in the vicinity were one or two stories high. A small tree, 25-feet high, stands about 50 feet south of the trailer. Except when the flow was southerly or easterly, representative wind data for a built-up suburban area should have been recorded.

The Fairview MASS unit was located next to the curb of Kennedy Boulevard on the east side of the Fair Ridge Shopping Center parking lot. A large commercial sign on a bearing of 210 degrees from the wind mast was only 30 feet away. The sign was supported by two columns 18 inches in diameter. The top of the sign was about 50 feet above the ground. All other structures that were as high as the wind sensors were 75 yards or more away. The area was near the western edge of the Palisades. Some influence of the ridge on wind speeds was expected.

During the initial part of the survey wind speeds were recorded in knots at all MASS units. Wind speed equipment was recalibrated from knots to miles per hour at Roselle and Willowbrook on Aug. 3 and at Fairview on Aug. 5, 1966. All data reduced and tabulated before these dates were converted from knots to miles per hour.

Meteorological data were employed in calculations for values used in various portions of the survey report. Examples of the calculation methods follow.

SO_2 Transport Rate

The transport of material from continuous emissions through a vertical cross-section of unit thickness and finite width is estimated with the equation:

$$N = W \Delta Z \Sigma \overline{U} \chi \sin D$$

where:

n in g/sec	total amount of material moving through vertical cross-section per unit time
W in m	width of cross-section
ΔZ in m	height interval used to calculate flux through vertical layers up to level of inversion
$\overline{U}$ in m/sec	mean wind speed for each layer
χ in g/m^3	mean concentration for each layer
D in degrees	angle between flight line and wind direction for each layer
Sin D	sin of D for each layer

Calculations for Outerbridge to Goethals Bridge (Arthur Kill)

15 June 1966 - SW Wind - 0600-0700 EST

$$N = W \Delta Z \Sigma \overline{U} \chi \sin D$$

Using three intervals

$W = 1.33 \times 10^4$

$\Delta Z = 90$ m

for levels:		a = 0 to 90 m	b = 90 to 180 m	c = 180 to 270 m
$\overline{U}$	=	2.9 m/sec	3.9 m/sec	5.4 m/sec
χ	=	0.21 ppm	0.15 ppm	0.10 ppm
	=	5.67×10^{-4} g/m^3	4.05×10^{-4} g/m^3	2.70×10^{-4} g/m^3
D	=	10°	30°	50°
sin D	=	0.174	0.500	0.766
$\overline{U} \chi \sin D$	=	2.86×10^{-4} g/sec per m^2	7.90×10^{-4} g/sec per m^2	11.18×10^{-4} g/sec per m^2
$\Sigma \overline{U} \chi \sin D$	=	2.194×10^{-3} g/sec per m^2		

$N = \underline{2.62 \times 10^3 \text{ g/sec}}$

using one interval

$\bar{U} = 4.1$ m/sec

$x = 0.15$ ppm $= 4.05 \times 10^{-4}$ g/m^3

$D = 30°$

$\sin D = 0.5$

$N = \underline{2.98 \times 10^3 \text{ g/sec}}$

Flux calculation -- West side Manhattan-Hudson-Pier 3 to 155th St.

15 June 1966

Mean of Two Runs - Between 0530 and 0822

one interval

$N = W \Delta Z \bar{U} \chi \sin D$

$W = 1.61 \times 10^4$ m

$\Delta Z = 5 \times 10^2$ m

$\bar{U} = 4.0$ m/sec

$x = 0.14$ ppm $= 3.78 \times 10^{-4}$ g/m^3

$D = 235^0 - 200^0 = 35°$

$\sin D = 0.573$

$N = (1.61 \times 10^4 \text{m})(5 \times 10^2 \text{m})(4 \text{ m/sec})(3.78 \times 10^{-4} \text{ g/m}^3)(0.573)$

$= \underline{6.97 \times 10^3 \text{ g/sec}}$

Flux calculation -- East River-Williamsburg Bridge to 145th St.

15 June 1966

0826 - 0836 EST

one interval

$N = W \Delta Z \succsim \bar{U} x \sin D$

$W = 1.25 \times 10^4$ m

$\Delta Z = 5 \times 10^2$ m

$\bar{U} = 4.0$ m/sec

$x = 0.29$ ppm $= 7.83 \times 10^{-4}$ g/m^3

$D = 235^0 - 200^0 = 35°$

$\sin D = 0.573$

$N = (1.25 \times 10^4)(5 \times 10^2)(4)(7.83 \times 10^{-4})(0.573)$ g/sec

$= 1.12 \times 10^4$ g/sec

By comparison

Flux East River	Flux Hudson River		Estimated Flux due to Manhattan
1.120×10^4 g/sec	6.97×10^3 g/sec	=	4.23×10^3 g/sec

Flux calculation -- West Shore Manhattan

22 June 1966 == 0800 EST

using one ht interval

$N = W \Delta Z \bar{U} x \sin D$

$W = 1.61 \times 10^4$ m

$\Delta Z = 6 \times 10^2$ m

$\bar{U}$ = 5.6 m/sec

x = 0.21 ppm = 5.67×10^{-4} g/m^3

D = 058° - 020° = 38°

sin D = 0.616

N = $\underline{1.89 \times 10^4 \text{ g/m}^3}$

Calculation of Hess or Chevron effect on CO sampling stations

Assumption: Source Strength (Q) for each plant 2000 g/sec (70,000 tons/yr)

$$\frac{\text{CO (g/m}^3)}{1158} = \text{CO (ppm)}$$

	Distance km	Stability	Wind Speed mps	u ppm	χ ppm	For Both Plants Multiply by [a]
Willowbrook	11.1	Neutral D	4	3.3	1.3	1 [b]
	11.1	Unstable F	2	6.8	5.8	1
Newark	23.0	Neutral D	4	1.3	<1	-
	23.0	Unstable F	2	4.6	4.0	1.9
Roselle	14.0	Neutral D	4	2.3	1	1.8
	14.0	Unstable F	2	6.1	5.3	1.9

Maximum Ground Level Concentration

	Distance from Stack				
	Km	miles	Wind Speed mps	$\frac{\bar{U}}{0}$	χ
Unstable	0.4	∼0.25	3	29.1	167
Neutral	2.0	∼1.25	4	16.0	69
Stable	8.0	∼5.0	7.3	7.3	6

[a] Based on assumption station is on centerline of both plumes.

[b] The plants are located so that Willowbrook cannot be on centerline of both plumes simultaneously.

DATA PROCESSING AND ANALYSIS

GENERAL

Methods of data handling and evaluation were an integral part of the overall project planning. Establishment of data handling techniques was particularly important in view of the number of agencies involved and the variety of data collected.

Because many thousands of data items would be processed during the project, use of a computer for storage and retrieval was mandatory. Card formats were designed or modified to permit utilization of current Abatement Branch programs for storage of the project data. Data formats were discussed with each participating agency to ensure that their data was compatible for processing through the system. In some instances, hand tabulations were necessary to transform the existing data into the required formats.

PROCESSING OF DATA

It was necessary to process data from stations under the cognizance of six agencies; the State of New York, State of New Jersey, New York City, New York University, City of New Rochelle, and the Public Health Service. These stations ranged in complexity from units capable of automatic sampling of up to nine air quality and meteorological data items to static stations monitoring SO_2 by the lead candle method. Additionally, data relative to emissions and air pollution effects were also collected and processed. A brief discussion of the processing of each of the main groups of data is presented.

Air Quality Data

For purposes of this discussion, air quality data are all data obtained through the sampling network, except meteorological data, which are discussed separately.

The flow diagram, Figure A-2 depicts the major elements of the data process from the time the sample is analyzed and a value recorded until the data are tabulated by the computer and analyzed. All air quality data from the participating agencies flowed through the Project Director's office at Raritan Arsenal. This provided central control to ensure prompt receipt of all data as scheduled. Any manual tabulations or calculations were completed at this time, and the data were then forwarded to Cincinnati, Ohio for key punching and computer storage. Computer tabulations were compiled for each pollutant by station and time. These tabulations were supplied to the participating agencies.

Meteorological Data

The meteorological data were processed in basically the same manner as the air quality data, the main differences being in the reduction procedures and the supplying agencies. Some agencies supplied the meteorological measurements directly, and they were then processed in the same manner as the air quality data. Other agencies, because of equipment differences, provided paper tapes that had to be read and evaluated manually prior to being key punched and stored in the computer. In addition to the data collected by the participating agencies, meteorological data were supplied by several stations operated by the U.S. Weather Bureau. These data were processed in the same way as the air quality data.

Emissions Inventory Data

Data were gathered for the emission inventory by means of questionnaires, plant visits, stack sampling and historical information. These data, because of their nature, were processed differently than the air quality or meteorological data. Detailed description of the emission inventory procedures are given in Appendix C.

Other Data

Additional data related to air pollution effects on the health or welfare of the inhabitants were gathered. These included data on vegetation studies, materials deterioration, and complaint records. These were manually tabulated rather than computerized.

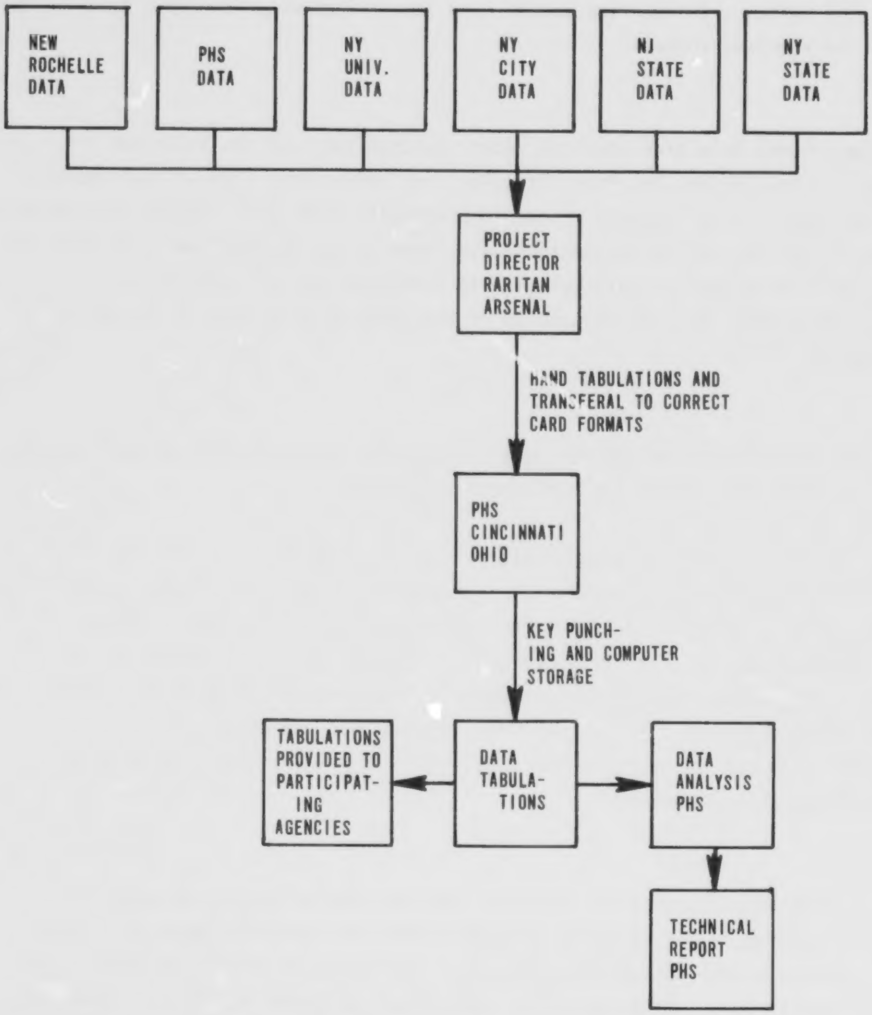
NEW ROCHELLE DATA
PHS DATA
NY UNIV. DATA
NY CITY DATA
NJ STATE DATA
NY STATE DATA
PROJECT DIRECTOR RARITAN ARSENAL
HAND TABULATIONS AND TRANSFERAL TO CORRECT CARD FORMATS
PHS CINCINNATI OHIO
KEY PUNCHING AND COMPUTER STORAGE
TABULATIONS PROVIDED TO PARTICIPATING AGENCIES
DATA TABULATIONS
DATA ANALYSIS PHS
TECHNICAL REPORT PHS

Figure A-2. Flow sheet air quality data handling and reduction.

Data Analysis

The tabulations present the data in formats that permit manual analysis; however, because of the large amount of data collected in this project, computer programs were written or existing programs modified to permit rapid data analysis. The more time-consuming and tedious tasks were given priority for computer programming. For purposes of description, data analysis techniques are divided into two classes; those involving a single pollutant or type of measurement, and those for which two or more pollutants or types of measurements are combined to provide more detailed information than can be obtained with one alone.

Single Pollutant Techniques

Averages - Two measures for the average were computed: the arithmetic mean and the geometric mean. The arithmetic mean is the sum of the measurements divided by the number of measurements.

The geometric mean is computed by finding the n^{th} root of the product of all the measurements. The geometric mean should be used to represent the data if the measurements are distributed log-normally, which is often the case with air pollution measurements. Computation of the average is important because it permits the use of a single number to represent a large amount of data.

Variability - As with the average, two measures of variability were computed: the standard deviation and the standard geometric deviation. These measures indicate the dispersion among the individual measurements. The standard deviation is used when the underlying distribution of the data is considered normal, whereas the standard geometric deviation is used if the measurements are distributed log-normally.

Frequency Distribution - Frequency distributions show what percent of the total measurements are less than a selected pollutant concentration or measurement level. A computer program performs the analysis and prints the resulting distribution. These distributions are valuable in that comparisons can be made with other data or criteria to determine relative degrees of pollution.

Combined Pollutant Techniques

Wind Roses - Wind roses depict the percentage of total measurements of wind direction for each of the 16 common compass points and the distribution of speeds for these wind directions. This information is necessary to explain transport of pollutants and to compare present conditions with past data. A computer program provides these wind roses.

Pollution Roses - Pollution roses combine meteorological data with pollution concentrations. A completed pollution rose provides a distribution of pollutant levels for each wind direction. Because pollution roses designate both direction and concentration they can be used to indicate the locations of significant pollutant sources. These may be either point or area sources; however, the pollution rose probably more accurately depicts intensities of emissions from area sources than those from point sources, inasmuch as a small deviation in wind direction may cause emissions from any particular point source to miss a given receptor completely. The wind factor would not be so critical in the case of area emissions. Other factors affect the validity of indications obtained from pollution roses; among these are:

1. The capacity of the air to disperse pollutants; this varies with wind speed, which tends to differ with directions.
2. The height of emissions and distances to sources.
3. The frequency of occurrence of specific wind directions. During some seasons certain wind directions occur infrequently; others with great frequency. These factors should be considered when interpreting pollution roses.

Upper Quartile Pollution Roses - The upper quartile pollution roses used in this report were developed in the following manner:

1. From all observed hourly concentrations, the upper quartile concentration was determined. The upper quartile concentration was defined as that concentration which divided the distribution of pollutant concentrations such that 25 percent of the values were equal to or greater than (and 75 percent equal to or less than) the selected concentration. In most instances it was not possible to select one value that would divide the data so that the upper quartile was precisely identified, because concentrations were calculated and recorded in discrete intervals.

Since all of the concentration values equal to that at the 75th percentile are included, most upper quartile contain more than 25 percent of all values. In fact the upper quartile value represented exactly the upper 25th percentile only in the case where but one observation was recorded at that value and it fell exactly at the 75th percentile.

2. The number of occurrences of upper quartile concentrations for each wind direction was tabulated and divided by the number of occurrences of each wind direction. Only hours when both air quality and wind data were simultaneously available were considered. The quotient was the percent of time upper quartile concentrations occurred with each wind direction. The results are presented graphically as upper quartile pollution roses.

Dosage Events - Dosage is the product of concentration and exposure duration; it is determined by multiplying the concentration (ppm) by exposure time (hours). Dosage analysis is presented elsewhere in this report and is tabulated by exposure times and computed dosage levels to show the number of instances the selected concentration was exceeded. This type of analysis is desirable to show the possible effects of concentration and time in contrast to concentration levels alone.

These techniques of data analysis provide means of presenting data so that logical interpretations of the results can be made. It is not possible, nor intended, to describe every aspect of data analysis in this report, but only to discuss briefly some of the more general techniques employed by the Public Health Service.

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Appendix B

AEROMETRY OPERATION AND TECHNIQUES

INTRODUCTION

The air monitoring network designed by the U.S. Public Health Service consists of automatic air monitoring and meteorological stations, combined with some semi-automatic continuous samplers and a nominal special sampling program. The design is integrated with existing air quality monitoring operations conducted by state, interstate, and local agencies to produce air pollution data for statistical analysis. The air monitoring network will be described and discussed under appropriate headings.

AIR MONITORING STATIONS

The five Public Health Service stations consist of a main station (Willowbrook), two satellite stations (Roselle and Fairview), and two substations (Fort Hamilton and Raritan). The main station is equipped with six automatic analyzers for continuous measurement of SO_2, NO_2, NO, CO, total oxidants, and total hydrocarbons. A complete wind measurement system and a digital data-logging system is also included.[B1/] The two satellite stations contain analyzers for SO_2 and CO, instruments for wind measurements, and data-logging equipment. The two substations are partially equipped with air monitoring instruments. The remaining 12 stations operated by the various agencies are fully or partially equipped to measure and log air pollution data. Table B-I lists the air monitoring stations and types of sampling employed at each site.

LEAD PEROXIDE SULFATION CANDLES

A lead peroxide sulfation candle network was initiated to determine an index of the activity of SO_2 in the atmosphere and to provide a correlation with SO_2 automatic monitoring instruments.

Two arcs of lead peroxide sulfation candles centered on the Bayonne station ring the station network. The inner arc has a radius of approximately 15 miles and consists of 36 lead peroxide candles stationed every 7-1/2 degrees, or about 2 miles apart. The outer arc has a radius of approximately 30 miles and consists of 19 candles located every 15 degrees, or about 8 miles apart. In addition, there were lead candles at several of the 17 monitoring stations in the core network.

The method is based on exposing PbO_2 paste in ambient air and measuring the sulfation caused by gaseous SO_2. After exposure, the material is stripped from the candles with sodium carbonate, and the amount of sulfate is determined by a turbidimetric procedure. The sulfation rate is reported as milligrams of SO_3 per 100 square centimeters per day. Correlation studies have shown that multiplying the lead candle value by 0.04 gives a good approximation of the SO_2 concentration in ppm. This factor when applied under applicable conditions permits gross estimates of SO_2 values.[B2/]

SPECIAL SAMPLING

Supplemental air monitoring data were obtained from special sampling activities initiated in the New York - New Jersey air pollution abatement investigation. The activities are listed and discussed.

A suspended particulates program was initiated to measure suspended particulates, sulfates, and acid content of the air. Eighteen high-volume filter samplers were located in pairs at nine major air monitoring stations in the study area. Locations are shown in Table B-I. Each sampler was electrically programmed to operate on a 24-hour-on, 48-hour-off schedule; thus, each pair of samplers sampled 2 days of each 3-day period.

Total suspended particulate was collected on 8- by 10-inch glass fiber filters over 24-hour periods. Results were based on differences between the initial and final weight of each filter and volume of air sampled. Data are reported as micrograms of total particulate per cubic meter of air.

Sulfates were determined by the turbimetric method. A portion of the filter was soaked and rinsed with distilled water. Sulfa Ver powder (Sulfa Ver Powder: Cat. No. 396 Hach Chemical Co., Ames, Iowa) was added and absorbance was read at a wavelength of 450 microns. Sulfate concentrations were determined from a calibration curve plotted to show standard sulfate concentrations against absorbance. Results are reported as micrograms of SO_4 per cubic meter of air.

Acid content was determined by placing a portion of the exposed filter in a solution containing a known quantity of dilute sodium hydroxide and titrating to a pH of 7. Total acidity was determined and acid content was reported as sulfuric acid.

The "Bag-Box" method was utilized to obtain grab samples of air for investigation of suspected sources of high air pollution and to check air monitoring stations for bias data. Such air samples were analyzed for SO_2, CO, and total hydrocarbons.

During August 1966, 16 grab samples of air were taken. Twelve samples were obtained in zones of concentrated industrial sources suspected of high air pollution emissions. Four samples were taken within a radius of 1 mile of the Willowbrook monitoring station on the north, east, south, and west quadrants.

INTERSTATE SANITATION COMMISSION

The Interstate Sanitation Commission made available their mobile sampling equipment for spot-sampling of SO_2. Sites were selected on Staten Island and in the northern portion of the study area to provide data not covered by the lead peroxide candle network. Eight locations were spot-sampled for SO_2 in September 1966.

SEQUENTIAL SO_2 ANALYZERS

During the month of August, continuous SO_2 measurements were conducted at the Raritan Depot station with sequential samplers run for 2-hour periods. Sulfur dioxide was determined by the there is often little variation. Zone J-4-9 in Middlesex County is a heavily industrialized zone containing a power plant, an oil refinery, and several industrial plants. Its maximum day emission density of 52.3 tons per square mile is only 5 percent higher than the minimum day density. In most zones, there is a much greater variation with space-heating demands. Maximum variations with space heating occur in Manhattan where some zones show daily minimum to maximum degree-day increments greater than 60 tons per square mile.

Zones containing steam-powered plants or other large point sources have markedly greater emissions than adjacent zones that are otherwise similar. Some of the variations in zone totals are due to the manner in which the zones were established. In most of New York City, each zone contains 1 square mile or less, whereas those in surrounding New York State counties and in New Jersey generally are larger. If a large point source, such as a steam-powered electric plant, is located in a zone of 1 square mile, the zone total becomes extremely large. An example is zone Y-2-6 in Brooklyn, only 0.2 square mile in area, it contains a power plant and has an emission density over 700 tons per square mile per day. If the same power plant were located in a zone of 6 or 7 square miles, the resultant emission density would be much smaller. For this reason, data contained in Appendix E must be considered in light of point source emissions.

There are in the study area 373 sources, each of which discharges 100 or more tons of SO_x per year. These point sources include power plants and major industrial sources, as well as commercial, governmental, and residential buildings. Of the total, 79 percent discharge 100 to 500 tons per year; 12 percent 500 to 1000 tons; 9 percent 1,000 to 4000 tons; and 10 percent more than 4,000 tons of SO_x per year. Power plants make up two-thirds of the over-4000-ton category, and industrial sources the rest. The 373 point sources discharge 841,000 tons of SO_x, more than half of the area total.

Point sources that discharge 100 or more tons of SO_x each year are plotted in Figure 19. A large percentage are located in proximity to, and on both sides of, the state line. The 34 largest point sources are shown on the maps in Figures 20, 21, and 22 where SO_x emission concentrations are shown for minimum, average, and maximum heating days.

Carbon Monoxide

The abatement activity survey showed that 5,296,000 tons of carbon monoxide (CO) are discharged to the atmosphere of the study area annually. Over 95 percent of this total is generated by gasoline-fueled motor vehicles. In New York, the motor vehicle fraction exceeds 99 percent.

The only significant nonvehicular sources of CO are industrial processes in New Jersey, which discharge about 3 percent of the annual total (Table XXXI). Only 1.1 percent of the total orginates from the combustion of heating fuels, primarily anthracite coal burned for residential space heating. Diesel-powered vehicles account for only 0.1 percent and refuse incineration 0.4 percent of the total.

Zones of greatest CO emissions generally are located in the four most heavily populated boroughs of New York City, but high CO discharge values are also found in some zones of Nassau, Westchester, Essex, and Hudson Counties (Figure 23). Emission concentrations of CO are highest

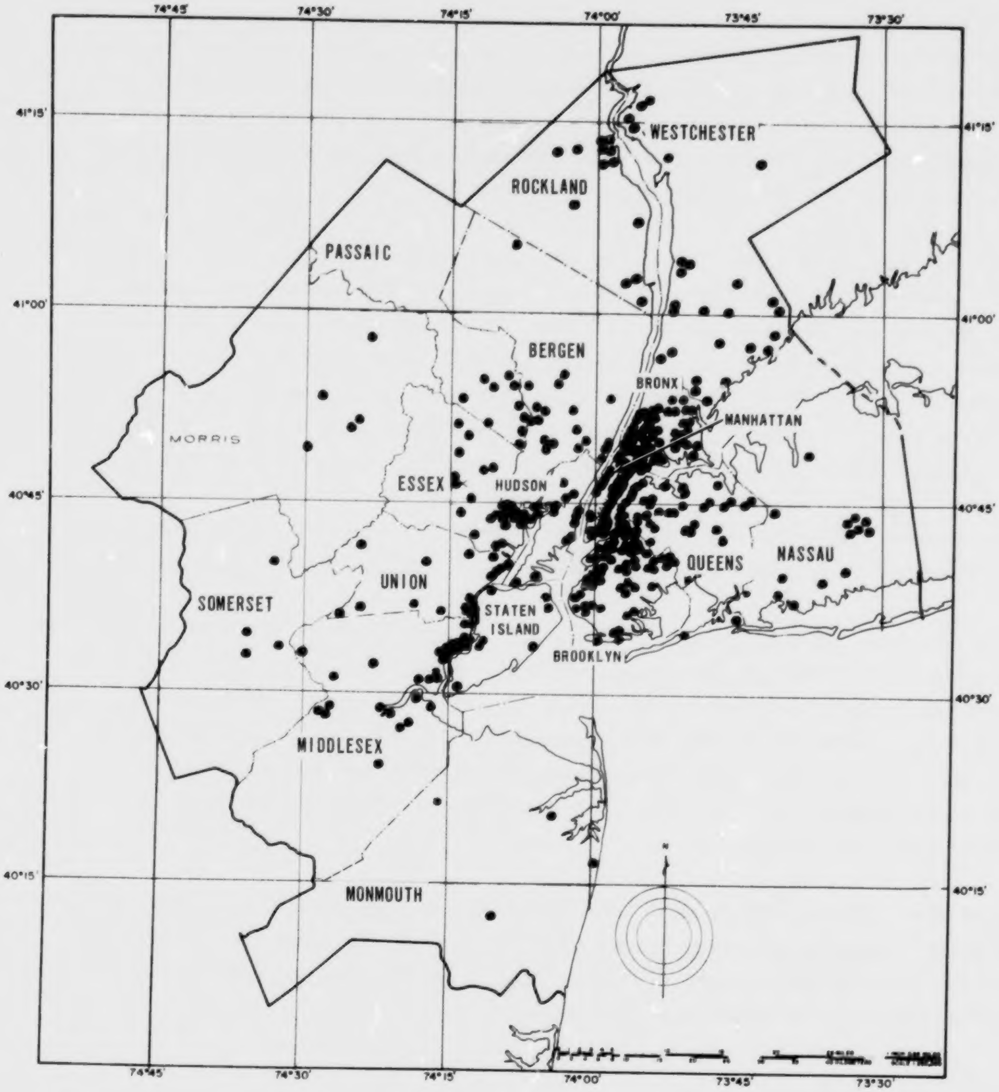
74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
41°15'
41°00'
40°45'
40°30'
40°15'
WESTCHESTER
ROCKLAND
PASSAIC
BERGEN
BRONX
MANHATTAN
MORRIS
ESSEX
HUDSON
QUEENS
NASSAU
UNION
SOMERSET
STATEN ISLAND
BROOKLYN
MIDDLESEX
MONMOUTH
N

Figure 19. Distribution of point sources that emit more than 100 tons of SO_x each year.

in Manhattan, where values in several zones exceed 60 tons per day per square mile. Middlesex County zones, in which petroleum refinery catalyst regenerators are located, have densities of 64 and 134 tons per day per square mile. Carbon monoxide emissions are considered to be essentially constant throughout the year, although measurable increases may occur during the heating season from inefficient small combustion units.

In determining CO emissions, it was assumed that all gasoline sold in a county also was consumed there. It is probable, however, based on comparison of gasoline sales and vehicle-mile data that much of the gasoline sold in the counties of Bergen, Essex, Hudson, and Union is consumed elsewhere, most likely in Middlesex County and New York City.

West-Gaeke SO_2 technique. The purpose of the program was to compare West-Gaeke SO_2 values with data from a continuous air monitoring station.

CALIBRATION OF MONITORING STATIONS

The stations of the air monitoring network are operated by many participating agencies in the study area. The instrumentation and analytical techniques used to obtain air quality data differed among the agencies. The accuracy and validity of the data are dependent upon the type and extent of its quality control.

During the months of July, August, and September 1966, static and dynamic calibration techniques were used by Public Health Service personnel at 16 stations of the continuous monitoring network to calibrate all instruments analyzing for SO_2, NO_2, NO, CO, total oxidants, and total hydrocarbons.[B3/] Instrument acceptability required an accuracy within ± 10 percent of results from manual analyses. All instruments were found to be within this acceptable range at the time of calibration.

REDUCTION OF WIND SPEED AND DIRECTION DATA (Willowbrook, Roselle, and Fairview Sites)

Hourly average wind speed was determined from the Mobile Air Sampling Station (MASS) strip-chart records of wind speed. The "equal area" method was used to extract and tabulate data to the nearest mile per hour. This method is a visual inspection technique by which a value of the wind speed that divides the oscillations of the wind trace into equal areas is selected from each time increment - in this case, 1 hour. The value selected was considered the mean speed for the hour. Speeds less than 0.5 mile per hour were tabulated as calm. Calms and missing and doubtful data were appropriately indicated on tabulations for computer processing. Corrections were applied, if appropriate, for drift of the recording and sensing system from zero.

Hourly average wind direction was determined from MASS record traces of the direction. A representative wind direction was ascertained for each hour by the "equal area" method described above. Calms and missing and doubtful data were appropriately noted on tabulation forms.

PERSONNEL

The aerometry Unit consisted of five full-time personnel: the unit chief, senior engineer, chemist, and two engineering technicians. Additional part-time help was provided during the summer months by three students.

The unit chief was responsible for overall supervision and coordination of routine and special air quality measurement activities including necessary liaison with other agencies. The senior engineer supervised operations of Public Health Service stations and special sampling activities and was responsible for liaison with his counterparts at the cooperating agencies concerning their sampling equipment, samples, data, etc. The chemist was responsible for laboratory support, including analyses and preparation of apparatus, equipment and chemical reagents. The two engineering technicians serviced the five Public Health Service stations and collected the samples. Technicians inspected the equipment daily to ensure that all systems were operating properly. The part-time students participated in a variety of activities, including the plant exposure program, bag-box sampling, data processing, and general maintenance of equipment.

FIELD SERVICING OF THE STATIONS

The size and complexity of the aerometry program required the establishment of standard operating procedures for each subphase of the program, e.g., calibration and servicing automatic instrumentation, bag-box sampling, changing lead peroxide candle samples and suspended particulate sampling. A summary of a typical month's scheduling for Public Health Service stations illustrates daily, weekly, and monthly activities.

Daily

1. All automatic instrumentation sites were visited. Reagents were added to the instruments as required. Instrument operations were checked and changes made as needed. All data charts were checked and any abnormalities noted. Malfunctions of equipment were detected and corrected.
2. High-volume filter samplers were serviced as needed. Generally, these samplers required attention only about once in 3 days.
3. The plant exposure chambers were visited every other day during the summer months to keep the plants watered and nourished, and to provide surveillance of plant damage.

Weekly

1. The data strip charts from the automatic instrumentation were cut and returned to the survey field station. These charts were then validated and forwarded to Cincinnati for processing.
2. A weekly preventative maintenance schedule was followed with all automatic instruments.
3. Plant pots in the exposure chambers were flushed with distilled water to prevent build up of salts in the support media. Fresh nutrient was added each week. Rubber strips used as indicators of oxidant concentration and the hygrothermograph charts in the plant chambers were changed weekly.

Monthly

1. Automatic wet-chemistry units were completly dismantled, cleaned, reassembled, and statically calibrated.
2. The 72 lead peroxide candle stations were visited and the candles changed.
3. Air flow volumes for high-volume filter samples were calculated.

Various programs such as calibration, grab sampling, and equipment maintenance and repair were conducted throughout the month as permitted.

REFERENCES

B1. Foster, K.E., Brooman, D.L. and Humphrey, P.A., "Integration of Air Monitoring, Meteorological, and Data-Logging Units into a Mobile Air Sampling Station." Presented at the 59th Annual Meeting of the Air Pollution Control Association, San Francisco, California, June 20-24, 1966. Paper No. 66-115.

B2. Hochheiser, S., "Methods of Measuring and Monitoring Atmospheric Sulfur Dioxide." PHS Publ. No. 999-AP-6, U.S. Department of Health, Education, and Welfare, Division of Air Pollution, August 1964.

B3. Christman, K.F., and Foster, K.E., "Calibration of Automatic Analyzers in a Continuous Air Monitoring Program." Presented at the Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 20, 1963, Paper No. 63-7.

TABLE B-I. STATION SUMMARY

			Instrumentation	
Agency	Station Code PHS	Address	Analyzer	Technique
Public Health Service (PHS)	001	Willowbrook Willowbrook State School 2760 Victory Boulevard Staten Island, N.Y.	SO_2	Conductivity (H_2O_2) (Beckman)
			OX	Colormetric (KI) (Beckman)
			NO_2	Colormetric (Saltzman) (Beckman)
			NO	Colormetric (Saltzman) (Beckman)
			CO	Infrared (4.56 microns) (Beckman)
			HC	Flame Ionization (Beckman)
			Wind Speed	
			Wind Direction	
			Wind Sigma	
			Particulate	Hi-Vol
			PbO_2 Candle	
			Plant Chamber	
			Effects Package	
PHS	002	Roselle Chestnut St. & East South Ave. Roselle Park, N.J.	SO_2	Conductivity (H_2O_2) (Beckman)
			CO	Infrared (4.65 microns) (Beckman)
			Wind Speed	
			Wind Direction	
			Wind Sigma	
			Particulate	Hi-Vol
			PbO_2 Candle	
			Plant Chamber	
PHS	003	Fairview Fair Ridge Shopping Center Bergen Ave. & Fairview Street Fairview, New Jersey	SO_2	Conductivity (H_2O_2) (Beckman)
			CO	Infrared (4.65 microns) (Beckman)
			Wind Speed	
			Wind Direction	
			Wind Sigma	
			Particulate	Hi-Vol
PHS	004*	Fort Hamilton Army Chaplain School Brooklyn, New York	SO_2	Conductivity (H_2O_2) (Beckman)
			Wind Speed	
			Wind Direction	
			Wind Sigma	
			Particulate	Hi-Vol
			PbO_2 Candle	
PHS	005	Raritan Raritan Depot Metuchen, New Jersey	SO_2	Conductivity (Davis)
			CO	Infrared (4.65 microns) (Beckman)
			HC	Flame Ionization (Davis)
			Particulate	Hi-Vol
			PbO_2 Candle	
New Jersey State	006	Bayonne Hudson County Park Bayonne, New Jersey	SO_2	Colorimetric (West-Gaeke) (Technicon)
			OX	Colorimetric (KI) (Technicon)
			NO_2	Colorimetric (Saltzman) (Technicon)
		Bayonne	NO	Colorimetric (Saltzman) (Technicon)
			CO	Infrared (4.65 microns) (Beckman)
			HC	Flame Ionization (Davis)
			CHO	Colorimetric (West-Gaeke) (Davis)
			Wind Speed	
			Wind Direction	
			Particulate	Hi-Vol
			PbO_2 Candle	
			Smoke Shade	
			Temperature	
			Relative Humidity	
			Barometric Pressure	
			Solar Radiation	
			Rainfall	

			Instrumentation	
Agency	Station Code PHS	Address	Analyzer	Technique
NJS	007	Newark Raymond Blvd. & McCarter Highway Newark, N.J.	SO_2	Colorimetric (West-Gaeke) (Technicon)
			OX	Colorimetric (KI) (Technicon)
			NO_2	Colorimetric (Saltzman) (Technicon)
			NO	Colorimetric (Saltzman) (Technicon)
			CO	Infrared (4.65 microns) (Beckman)
			HC	Flame Ionization (Davis)
			CHO	Colormetric (West-Gaeke) (Technicon)
			Wind Speed	
			Wind Direction	
			Particulate	Hi-Vol
			PbO_2 Candle	
			Smoke Shade	
			Temperature	
			Relative Humidity	
			Barometric Pressure	
			Solar Radiation	
			Rainfall	
NJS	021*	Ancora N.J. State Hospital Hammonton, N.J.	SO_2	Colorimetric (West-Gaeke) (Technicon)
			OX	Colorimetric (KI) (Technicon)
			NO_2	Colorimetric (Saltzman) (Technicon)
			NO	Colorimetric (Saltzman) (Technicon)
			CO	Infrared (4.65 microns) (Beckman)
			HC	Flame Ionization (Davis)
			CHO	Colorimetric (West-Gaeke) (Technicon)
			Wind Speed	
			Wind Direction	
			Particulate	Hi-Vol
			PbO_2 Candle	
			Smoke Shade	
			Temperature	
			Relative Humidity	
			Barometric Pressure	
			Solar Radiation	
			Rainfall	
New York State	016	New Rochelle 30 Church St. New Rochelle, N.Y.	SO_2	Colorimetric (West-Gaeke) (Sequential)
			CO	Infrared (4.65 microns) (Beckman)
			Wind Speed	
			Wind Direction	
			Particulate	Hi-Vol
			PbO_2 Candle	
New York City	014	121st St. Lab. Bureau of Laboratories 170 E. 121st Street Manhattan, N.Y.	SO_2	Conductivity (Davis)
			NO_2	Colorimetric (Wilson-Saltzman)
			CO	Infrared (4.65 microns) (MSA)
			HC	Flame Ionization
			Particulate	Hi-Vol
			PbO_2 Candle	
			Smoke Shade	
NYC	013	Central Park Belvedere Tower Manhattan, N.Y.	SO_2	Conductivity (Davis)
			HC	Flame Ionization
			PbO_2 Candle	
			Smoke Shade	
NYC	012	New York University 1911 Osborn Place Bronx, New York	SO_2	Conductivity
			Wind Speed	
			Wind Direction	
			Smoke Shade	
New York University	008	Albert Einstein Medical School Bronx, N.Y.	SO_2	Conductivity (Davis)

Agency	Station Code PHS	Address	Instrumentation	
			Analyzer	Technique
NYU	009	Prospect Park Tennis Club House Prospect Park Brooklyn, N.Y.	SO_2	Conductivity (Davis)
NYU	010	Jersey City Pollock Hospital N.J. College of Medicine Jersey City, N.J.	SO_2	Conductivity (Davis)
NYU	011	J.F.K. J.F.K. Airport, Hanger II Jamaica, N.Y.	SO_2	Conductivity (Davis)
NYU	029	Passaic, City Hall 101 Passaic Avenue Passaic, New Jersey	SO_2	Conductivity (Davis)
Interstate Sanitary Commission (ISC)	029	Willowbrook 2760 Victory Blvd. Staten Island, N.Y.	SO_2 Smoke Shade	Conductivity
ISC- Two mobile Units		ISC 10 Columbus Circle New York, New York	SO_2	Conductivity
NYS	015	Suffern Suffern, New York	Wind Speed Wind Direction	
NYC	022	Samuel Gomper, H.S. 445 Southern Blvd. Bronx, New York	SO_2 Smoke Shade	Conductivity
NYC	023	59th Street Bridge Plaza Manhattan, N.Y.	SO_2 NO_2 CO HC Particulate Smoke Shade	Conductivity Colorimetric Infrared Flame Ionization
NYC	024	Shearton Whitehall Bldg. 17 Battery Place Manhattan, N.Y.	SO_2 NO_2 Smoke Shade	Conductivity Colorimetric
NYC	025	57th St. & 10th Ave. Manhattan, N.Y.	Smoke Shade	
NYC	026	Firehouse 10-42 - 47th Ave. Queens, N.Y.	SO_2 Smoke Shade	Conductivity
NYC	027	Brooklyn Polytechnic Institute 333 Jay Street Brooklyn, New York	SO_2 Smoke Shade	Conductivity
NYU	030	Geophysical Science Laboratory 2455 Sedgwich Avenue Bronx, New York	SO_2	Conductivity
NYU	031	Apt. of Braithwaite 645 W. 160th Street New York, N.Y.	SO_2	Conductivity
NYU	032	Apt. of Ricci 411 E. 239th Street Bronx, New York	SO_2	Conductivity
U.S. Weather Bureau (USWB)	017	Newark Airport Newark, N.J.	Wind Speed Wind Direction	
USWB	018	LaGuardia Airport New York	Wind Speed Wind Direction	
USWB	019	Teterboro Airport New Jersey	Wind Speed Wind Direction	
USWB	020	Westchester County Airport New York	Wind Speed Wind Direction	

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*Not on line in time to supply complete data for summer 1966.

Appendix C

EMISSIONS INVENTORY PROCEDURE

Various means were used to quantify carbon monoxide and sulfurous air contaminants released from sources in the study area. Where emissions were of significant magnitude, efforts were made to obtain exact figures, usually by direct interview or mail survey. For the vast number of small sources -- automobiles, trucks, medium to small residences, and small industrial and commercial establishments -- it was not possible to contact each source separately. To obtain accurate figures on the latter categorie it was necessary to employ traffic study data and census figures on population, dwelling units, and manufacturing operations and to ascertain fuel usage by typical users in the area.

Data for New Jersey and New York City were compiled during a 3-month period from June through August 1966. The Public Health Service and New York State emission inventory procedures C1,C2/ were employed with some modifications. The New Jersey program was operated out of the Raritan Arsenal by personnel of the Public Health Service and the New Jersey State Department of Health. The New York City program was conducted, in large part, out of an office at 346 Broadway by the Public Health Service, the New York State Air Pollution Control Board, and the New York City Department of Air Pollution Control personnel.

Surveys of air pollution sources in Westchester, Rockland, and Nassau Counties were conducted in 1961 and 1962.C3,C4,C5/ Results were published by New York State. Power plant emissions were updated to 1965. Other stationary source data were used as shown in the New York State reports.

Essentially all the sulfurous air contaminants and CO emitted in the study area are from the burning of automotive and combustion fuels and from industrial processes. The emissions inventory consisted of evaluating the consumption of gasoline, diesel fuel, coal, fuel oil, and natural gas and of determining emissions from refuse incineration and process industries. Emissions were determined directly from the fuel input to the equipment for both automotive and stationary sources. Emission factors and sulfur contents are listed in Table C-I.

Annual consumption of all fuels and process emissions in each zone, except for the three outlying New York counties, were determined for the calendar year 1965. Daily emissions were calculated for minimum, average, and maximum degree-days. Emissions of sulfur compounds are reported in terms of tons of SO_2 per square mile for each inventory zone during minimum, average, and maximum space-heating days. There was considered to be no significant variation in CO emissions and all figures are for average days in tons per square mile.

POINT SOURCES

Each industrial site, governmental building, apartment house, etc., from which 100 or more tons of SO_2 were emitted per year was considered a point source. It was not necessary to set a point-source

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standard for CO inasmuch as the area contains only three significant nonvehicular sources of this contaminant. These three sources, two petroleum refineries and one chemical plant, are also point sources of SO_2.

TABLE C-I

EMISSION FACTORS AND SULFUR CONTENTS OF PRINCIPAL FUELS USED IN STUDY AREA AND EMISSION FACTORS FOR INCINERATION

	Sulfur Content, %	Emission Factors	
		SO_x as SO_2	CO
Anthracite Coal	0.625	25 lb/ton	50 lb/ton
Bituminous Coal	1.875	75 lb/ton	1 lb/ton
Distillate Oil	0.575	85 lb/1000 gal	2 lb/1000 gal
Residual Oil	2.45	390 lb/1000 gal	0
Natural Gas	Neg.	0.6 lb/10^6 ft^3	0.4 lb/$10^6 ft^3$
Diesel Fuel	0.30	45 lb/1000 gal	60 lb/1000 gal
Gasoline	0.03	5 lb/1000 gal	2910 lb/1000 gal
Municipal Incinerators		1.9 lb/ton	0.7 lb/ton
Small or Single Incinerators		0.3 lb/ton	25 lb/ton
Open Burning Incinerators		0.3 lb/ton	0 lb/ton

MOTOR VEHICLES

The principal sources of CO in the study area are motor vehicles. By far the largest quantity is emitted from gasoline-powered vehicles, which are much more numerous than diesel-powered vehicles and produce significantly greater concentrations of CO in exhaust gases.

VEHICLE-MILE DATA

The Tri-State Transportation Commission made available 1963-1964 vehicle-mile data for almost the entire study area (excluding portions of outlying New Jersey counties).[C6/] These data were furnished as vehicle-miles per square mile per average calendar day on a square-mile grid pattern. Vehicle-miles for outlying areas were estimated from those of similar areas.

TRANSFER TO EMISSION ZONES

Tri-State data were converted to the irregular zone boundaries used in New Jersey and in Nassau County and to the square-mile zones of New York City. This was accomplished with overlay maps. For Westchester and Rockland Counties gasoline and diesel fuel figures were taken from New York State reports[C3,C4/] and apportioned by zones. The transfer technique was probably more accurate in New Jersey and Nassau County than in New York City, since the zones in the former were generally larger than the 1-square-mile zones of New York City. The Tri-State grid pattern was at a 30-degree angle with the New York University grid pattern[C7/] used in our inventory of New York City. Much interpolation was, therefore, necessary to convert these data to the New York City zones.

GASOLINE AND DIESEL FUEL USAGE

To determine the amount of gasoline consumed in each zone, it was necessary to estimate the ratio of gasoline- to diesel-powered vehicles, as well as the average vehicle speed in each zone. Gasoline consumption per zone was calculated by use of conversion figures shown in Table C-II. In New Jersey, TABLE C-II

AVERAGE VEHICLE SPEEDS AND GASOLINE CONSUMPTION RATES IN STUDY AREA[a]

County	Average Speed, mph	Gasoline Consumption, gal/mi
New Jersey[b]		
Bergen	<9	0.117
Essex	<9	0.137
Hudson	<9	0.122
Middlesex	35	0.051
Monmouth	33	0.053
Morris	27	0.059
Passaic	17	0.077
Somerset	>40	0.033
Union	<9	0.111
New York[c]		
Bronx	15	0.082
Brooklyn	12	0.092
Staten Island	20	0.070
Manhattan	9	0.109
Queens	12	0.092
Nassau	15	0.082

a. The relationship between average speed and gasoline consumption was determined by A.D. May, Jr., "A Friction Concept of Traffic Flow", Highway Research Board Proceedings, Vol. 38, 1959.

b. Gasoline consumption was calculated from county sales totals and vehicle-mile data. Average speeds were derived from May's relationship.

c. Average speeds were determined from recommendations of the Tri-State Transportation Commission.

county gasoline gallonage totals were available[C8,C9] and were used as a check on consumptions determined from the Tri-State data. It was assumed that diesel-powered vehicles in the study area all consumed fuel at the same rate (0.18 gallon per mile)[C10] and accounted for 3 percent of the vehicle-miles in each zone.

PROCESS SOURCES

Emissions from industrial processes were determined from plant inspections and information solicited from plant officials. Sources were selected for inspection on the basis of number of employees and type of industry, as well as reports of state and local officials. All known chemical plants, petroleum refineries, foundries, and acid plants of any size were contacted. In many instances, company officials had data available on stack emissions of sulfur oxides. For the most part, the data acquired from plant officials were reasonable for the sizes of the plants and the types of operations being conducted; if the figures did not appear plausible, additional estimates were made by Public Health Service engineers.

COMBUSTION FUELS

Sources were delineated in terms of fuel type and user type to determine the quantity of the various combustion fuels burned during different times of the year. Bituminous and anthracite coal, distillate and residual oil, and natural gas are the only fuels used in significant quantities in the project area. Fuel sources were listed as residential, commercial and govermental, power plant, industrial. Residential sources included all dwellings from one-family homes to mult-story high-rise apartment buildings.

The portion of fuel burned for space heating and that burned on a steady day-to-day basis throughout the year were determined. It was found that essentially all commercial and governmental fuel, much residential fuel, and some industrial fuel was burned for space-heating purposes. At power plants fuel is burned at a reasonably constant daily rate. The variable use of fuel for space heating determines the differences in emissions on minimum, average, and maximum degree-days.

POINT SOURCES

Any fuel-burning source generating 100 tons of SO_2 per year is considered a point source. For example, to be in the point-source category requires the burning of 500,000 gallons of residual oil with a sulfur content of 2.45 percent, 2,670 tons of bituminous coal with a sulfur content of 0.575 percent or 8,000 tons of anthracite coal with a sulfur content of 0.625 percent annually.

RESIDENTIAL FUEL USE IN NEW JERSEY

Fuels consumed by residential sources were determined from information available on population, dwelling units, and the relative use of coal, oil, and natural gas.[C11,C12,C13/] Smaller residential units all were assumed to use natural gas, distillate oil, or anthracite coal for heating. Larger apartment buildings, i.e., 50 units or more, were assumed to use residual fuel oil or bituminous coal.

Population

1965 Census data are listed in the Rand McNally Commercial Atlas and Marketing Guice - 1966 Edition. Population figures were also available by census tract from the 1960 Census.[C13/] Wherever the Rand McNally figures showed an increase of 5 percent or greater since 1960, census tract totals were updated.

For certain zones, 1965 data were not available. Where current maps showed considerable development in these areas, estimates were made of the increase. These were based on overall county percentage increases since 1960, unless more specific information was available. Some census tracts cover more than one emission zone. In these cases, population and dwelling units were apportioned on the basis of topographical maps.

Dwelling Units

Occupied dwelling units are listed in the 1960 Census of Housing by Census tract.[C12/] These dwelling totals were increased proportionately in accordance with the Rand McNally figures wherever population totals had increased more than 5 percent since 1960. Monmouth County census data were not available for 1960 except for cities and towns. Where no dwelling unit totals were available, the overall Monmouth County ratio of 2.89 persons per dwelling unit was used. Figures were updated to 1965 levels.

Residential Use of Coal - New Jersey

The numbers of New Jersey occupied dwellings using coal (anthracite and bituminous) in 1960 were developed by the Public Health Service through the Bureau of the Census. In the New Jersey counties, overall county percentages of dwellings using coal were used to determine the total dwelling units heated with coal in each zone. In Woodbridge Township of Middlesex County an accurate figure was available based on a 1965 survey by local officials.

Reliable sources report that 90 percent of all northeastern New Jersey residential coal users burn anthracite coal. It is also estimated that very few residences built since 1960 use coal. Therefore, the 1960 figures for residential dwelling units were not updated.

It has been determined that the average coal-burning dwelling unit in northeastern New Jersey requires 7 tons of either bituminous or anthracite coal per year. It was assumed that all coal used in dwelling units was used only for space heating.

Residential Use of Oil - New Jersey

The number of New Jersey dwelling units burning fuel oil was determined in the same manner as coal users. It was estimated that 20 percent of all residences built since 1960 use fuel oil for space heating. Therefore, 20 percent of the dwelling unit increase since 1960 was allocated to this fuel.

It was assumed that residential structures with more than 50 dwelling units use residual fuel oil and that all others use distillate fuel oil. From data in the 1960 Census of Housing,[C12,C13] it was possible to estimate the number of it was possible to dwelling units located in structures of 50 or more units.

New York University personnel calculated that each oil-burning dwelling unit in northern New Jersey consumes either 1,600 gallons of distillate or 760 gallons of residual oil.[C1] The difference cannot be accounted for solely on the basis of the heating value of each fuel and reflects the fact that less heating is required per dwelling unit in large apartment houses than in smaller buildings. Much of the distillate oil is burned in single family-homes. It was assumed that 250 gallons per unit of either distillate or residual oil were used for water heating, air conditioning, and cooking purposes. The differential fuel (1,350 or 510 gallons) represents the space-heating requirement for each dwelling unit.

Residential Use of Natural Gas - New Jersey

The number of dwelling units using natural gas was determined from the 1960 Census in the same manner as that described for coal and fuel oil. Reliable sources estimate that 70 percent of all dwelling units constructed in the area since 1960 are heated with natural gas. Therefore, 70 percent of the total dwelling-unit increase since 1960 was allocated to natural gas.

It is estimated that 150,000 cubic feet of natural gas is required per dwelling unit annually for space heating, water heating, and cooking purposes in this area. Actual usage totals furnished by natural-gas suppliers in the area indicated 226,500 cubic feet of natural gas was used per dwelling unit heated with natural gas. The larger figure reflects the fact that many homes, heated with coal or oil, use natural gas for cooking and heating water. The differential quantity of natural gas is consumed in such residences. Because of the extremely low quantity of sulfur oxides and CO generated by burning natural gas, it was not deemed necessary to locate these users accurately. In all probability, there is a reasonably equal distribution of both types of natural-gas users in the emission zones.

RESIDENTIAL FUEL USE IN NEW YORK CITY

Populations, dwelling unit totals, and numbers of dwelling units using each fuel were obtained for the year 1962 from an unpublished report of New York University entitled, "Source Inventory for Urban Air Pollution Dynamics."[C7/] The New York University employed essentially the same techniques for inventorying as those used in the New Jersey program.

Residential Use of Coal - New York City

From the gas utilities and the Coal Committee of the Fuel Dealers Association of New York City, it was learned that there had been a sharp decrease in residential coal burning since 1962 when data were compiled by New York University. Based on this information, the numbers of residential units burning coal (NYU Study) were decreased by 60 percent in the Bronx and Manhattan, and by 67 percent in the other three boroughs. Each coal-burning dwelling was assumed to burn 3.85 tons annual of either bituminous or anthracite coal, with 95 percent of the total being anthracite.

Residential Use of Oil - New York City

Information from several sources indicated adjustments were needed in 1962 New York University dwelling unit totals.[C7/] In general this required slight increases. Each dwelling unit was assumed to burn 730 gallons of residual oil or 1400 gallons of distillate oil annually. As in New Jersey, it was assumed that 250 gallons of oil are used annually for water heating, etc. in a dwelling unit.

Residential Use of Natural Gas - New York City

Individual county totals for New York were supplied by gas utilities. The gas was apportioned to the zones based on the dwelling-unit totals.

INDUSTRIAL FUEL USE IN NEW YORK CITY

Point Sources

Industrial users considered to be possible point sources were interviewed or sent questionnaires by mail. Estimates were obtained on the percentages of each fuel used for space heating. Based on these estimates, 13 percent of the sulfur oxides from industrial fuel was attributed to space heating.

Homogenous Industrial Fuel

It was necessary to estimate the amount of fuel oil and coal used by smaller industrial sources, i.e., those producing less than 100 tons of SO_2 per year. U.S. Census of Manufacturing data were available for the New York Standard Metropolitan Statistical Area (SMSA) for the year 1962.C14/ This publication provides fuel totals by SMSA for all industries except steam powered plants and those industries that produce their own fuel, e.g., refineries and coke plants. More accurate natural gas data were available from utilities. In each county, the point-source totals for each fuel were subtracted from the estimates for the total county. The remaining homogenous background figure was then distributed over the emissions zones within the county in proportion to the degree of industrialization.C15/ U.S. Geological Survey topographical maps, the New Jersey Industrial Directory,C16/ and a knowledge of the area were used to estimate the degree of industrialization in each zone.

INDUSTRIAL FUEL USE IN NEW YORK CITY

The estimate of industrial fuel usage in New York City was made in essentially the same manner as in New Jersey except that the New York City Department of Planning land-use maps rather than topographical maps were used to determine the degree of industrialization in each zone. Fifty percent of the industrial fuel SO_x was attributed to space heating.

STEAM-POWERED ELECTRICITY-GENERATING POWER PLANTS

Fuel-use figures were obtained directly from the electric utilities in the study area. Amounts of residual oil, bituminous coal, and natural gas used at all power-generating stations were provided together with sulfur contents of each fuel at each station.

COMMERCIAL AND GOVERNMENTAL FUEL USE IN NEW JERSEY

Point Sources

All Federal,C17/ state, and local governmental agencies and large private institutions were surveyed by mail or interview. Information contained in returned questionnaires was used to estimate by comparison the emissions from those entities that did not return the questionnaires.

Homogenous Commercial and Governmental Fuel

The homogenous fuel usage by commercial and governmental establishments was determined essentially as the difference between area totals and that accounted for by other sources, i.e., industrial and residential. County fuel oil and coal totals were estimated from data of Rohrmane, et al., C18/ and the Bureau of Mines.C19/ From these latter figures, the industrial and residential totals were subtracted. That remaining was considered as the total commercial and governmental usage for the particular county. After the point-source fuel usage was subtracted, the remaining totals were apportioned to the emission zones based on a knowledge of the area, the New Jersey State Industrial Directory,C16/ U.S. Geological Survey topographical maps, and information procured from interviews with municipal officials and mail questionnaires. Natural-gas data were supplied by gas utilities and apportioned in the same manner.

COMMERCIAL AND GOVERNMENTAL FUEL USE IN NEW YORK CITY

Essentially the same procedure was used to determine commercial and governmental fuel usage in New York City as was used for New Jersey. It was possible, however, to obtain exact figures from New York City agencies, which accounted for much of the fuel burned. Governmental fuel oil and coal totals obtained from New York City agencies for 1964 were updated 10 percent. Commercial fuel oil and coal totals were obtained through private correspondence. The homogenous fuel totals were apportioned on the basis of information obtained from land-use maps rather than topographical maps.

REFUSE INCINERATION

The burning of combustible refuse is not considered a large source of sulfur oxide or CO pollution. The following approximate methods were used to determine the quantities of refuse burned in the study area.

1. Residential incineration in New Jersey - It was assumed that 400 pounds of combustible refuse per person was burned annually in rural areas.[C2] For purposes of determining emission factors, this incineration was put in the open-burning category. It was assumed that no residential refuse was incinerated in urban areas.

2. Residential incineration in New York City - These data were taken directly from the New York University report.[C7]

3. Industrial incineration in New Jersey and New York City - Information on refuse disposal was obtained by interview and mail questionnaire in both areas. Background incineration by small industrial was neglected.

4. Commercial and governmental incineration in New Jersey - Refuse disposal information and pertinent figures regarding hospitals and schools were obtained through mail questionnaires. It was assumed that 0.8 ton of refuse per classroom was burned at each school where incineration was practiced.[C2] At each hospital an estimated 1.25 tons per bed was burned annually. Large municipal incinerations were contacted directly.

5. Commercial and governmental incineration in New York City - All refuse disposal information was procured by mail questionnaire or by contacting New York City agencies. Accurate totals were made available for all municipal incinerators.

DAILY VARIATIONS IN SULFUR OXIDE RESULTING FROM SPACE HEATING

Sulfur oxide emissions were determined for minimum, average, and maximum heating days in 1965. For each zone, sulfur oxides emissions were divided into a variable fraction resulting from space heating and a steady fraction resulting from operations that are essentially constant throughout the year. The variable sulfur oxides was assumed to consist of:

1. All commercial and governmental sulfur oxides.
2. A portion of the industrial fuel sulfur oxides, 50 percent in New York City and 13 percent in all other areas.

3. A portion of the residential sulfur oxides (Table C-III for county factor).

Residential space-heating factors as listed in Table C-III were estimated on the basis of the relative quantities of distillate and residual fuel oil burned in the particular county. As noted previously, those dwelling units heated with residual oil use relatively less fuel for space heating than units heated with distillate oil. Water heating and other non-space-heating uses are considered constant for both types of users. All coal is considered to be used for space heating.

TABLE C-III

RESIDENTIAL SPACE HEATING FACTORS

County	SO_x Emissions From Space Heating % of residential	SO_x Emissions From Water Heating Cooking, etc. % of residential
New Jersey		
Bergen	85	15
Essex	86	14
Hudson	86	14
Middlesex	86	14
Monmouth	86	14
Morris	86	14
Passaic	87	13
Somerset	86	14
Union	87	13
New York		
Bronx	71	29
Brooklyn	74	26
Staten Island	74	26
Manhattan	68	32
Queens	75	25
Nassau	85	15
Rockland	86	14
Westchester	76	24

Steady day-to-day SO_x emissions were considered to consist of:

1. All process sulfur oxides,
2. All power plant sulfur oxides,
3. A portion of industrial sulfur oxides, 50 percent in New York City and 87 percent in all other areas,

4. A portion of residential sulfur oxides (Table C-III for county factor),
5. All refuse incineration sulfur oxides,
6. All vehicular sulfur oxides.

On a minimum heating day, it was assumed that there was no space heating. Therefore, emissions are represented by the above-mentioned steady sulfur oxides figure.

Average and maximum heating day totals were determined by adding steady emissions to variable emissions during respective days. Meteorological data acquired from the U.S. Weather Bureau were used to determine these fractions of the yearly variable sulfur oxides emitted during average and maximum heating days. The following formulas were used to calculate daily sulfur oxides emissions:

Minimum day = steady SO_x, tons per day

Average day = minimum day + variable SO_x, (tons/year)(21/5,070)

Maximum day - minimum day + variable SO_x, (tons/year)(48/5,070)

The factor 21/5,070 represents the fraction of annual degree-days occurring on the average heating day. The value 21 is the mean degree-days for all days of the year with average temperature less than 65°F, the value 5,070 is the cumulative degree-days for the year 1965. The factor 48/5,070 represents the fraction of annual degree-days occurring on coldest days; the value 48 is the normalized average degree-days for the 4 coldest days of the year. Daily tonnages were divided by the zone areas to yield emission concentrations in terms of tons of sulfur oxides per square mile.

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C16. "New Jersey State Industrial Directory," New York, N.Y., 1966.

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C18. "Residual Fuel, Air Pollution - A Growing Problem." Rohrman, F.A., Ludwig, J.H., and Steigerwald, B.J. Oil and Gas Journal, June 27, 1966.

C19. "Minerals Yearbook," Fuels Volume, U.S. Department of Interior, Washington, D.C., 1962 and 1964 Editions.

Excerpt from Record of New York-New Jersey Interstate Air Pollution Abatement Conference January 10, 1967

The information given in Appendix D of the report, "New York-New Jersey Air Pollution Abatement Activity" concerns a series of source tests conducted by personnel of the Abatement Branch at one of the seven calcining operations of the National Lead Company, Sayreville, New Jersey. The calcining operations, which create a distinct visible plume, are believed to be a major source of sulfur oxide emissions at this plant.

A significant difference was found between the sulfur oxide emissions reported by the Company and those indicated by our tests data. This difference prompted the Public Health Service to schedule a meeting with technical personnel of the National Lead Company to discuss possible discrepancies. It was informally agreed between our field office at Metuchen, New Jersey, and plant officials that these data would not be published preceding resolution of the differences.

Unfortunately, as occasionally happens when operations are scattered and timing is critical, communications broke down among our Metuchen field office, our Washington Headquarters and our Cincinnati supporting facilities. We regret sincerely the premature publication of the information, since such a meeting has not yet been held.

National Lead Company's voluntary cooperation in our testing program is genuinely appreciated, and we are sure this matter will be mutually and satisfactorily resolved.

Meanwhile, we are requesting deletion from the conference record of all reference on page 131 to tests at National Lead Company; further, we will publish an appropriate erratum and provide a copy of this statement for the Company's records.

It is significant to note that, in computing total emissions to the New York-New Jersey interstate atmosphere, the information in Appendix D was not used. Instead, we used emission information as voluntarily supplied by the Company.

Appendix D

SUMMARY OF ATMOSPHERIC EMISSION TESTS

Two sets of tests were made by members of the Field Investigations Section, Abatement Branch, National Center for Air Pollution Control, Public Health Service, to determine the atmospheric emissions from specific sources in the survey area.

The first set of tests was conducted at the National Lead Company's Titanium Division in Sayreville, New Jersey, on Sept. 8 and 9, 1966. This plant, with a capacity of about 157,000 tons of titanium dioxide per year, utilizes the sulfate process in which sulfuric acid is added to titanium ore to yield titanium sulfate. The compound is heated in a rotary kiln that yields the product, titanium dioxide. Gaseous sulfur compounds and particulates are exhausted from the kiln.

Kiln gases pass through a water scrubber, electrostatic precipitators, and a final gas-washing tower before discharge to the atmosphere.

The amounts of air pollutants emitted from a single calcining operation are shown in Table D-I. Inasmuch as the plant has seven calciners, total estimated emissions would be 7 times those shown in Table D-I.

TABLE D-I

ATMOSPHERIC EMISSIONS FROM ONE CALCINING OPEPATION

Pollutant	Emissions, lb/day
Sulfur dioxide	6,900
Sulfur trioxide	310
Particulate	380
Acid mist	180

A second series of emission tests was conducted on two flue-fed incinerators. These incinerators, located in the New York City Gowanus Project, were tested on Sept. 15, 16, 17, 1966.

Each incinerator was a single-chamber, natural-draft type into which refuse is thrown through doors in the flue on each floor of the building. The smaller unit, in a six-story apartment house, served 73 people; the larger unit served 396 people in a 14-story apartment house.

Atmospheric particulate emissions were determined at each unit during normal burning periods and are shown in Table D-II.

TABLE D-II

PARTICULATE EMISSIONS FROM TWO FLUE-FED INCINERATORS

Building	Run No.	Particulate Emissions, lb/day
Six Story	1	1.5
	2	1.2
	3	0.2
Fourteen Story	1	11.3
	2	6.8
	3	5.7

Appendix E

TABLES AND FIGURES

This appendix contains tables and figures pertinent to the Technical Report.

Included are the following:

1. Emission inventory data by county and emission zone.
2. Emission inventory zone maps.
3. Frequency distributions of hourly sulfur dioxide concentrations.
4. Frequency distributions of daily sulfur dioxide concentrations.
5. Frequency distributions of hourly carbon monoxide concentrations.
6. Pollution roses for sulfur dioxide.
7. Pollution roses for carbon monoxide.

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Bergen County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-1-1	20.5	Neg.	Neg.	Neg.	0.6
J-1-2	3.8	1.2	1.8	2.4	4.6
J-1-3	10.4	Neg.	0.1	0.3	2.5
J-1-4	10.1	Neg.	0.2	0.4	3.5
J-1-5	9.9	Neg.	0.2	0.4	3.2
J-1-6	9.4	Neg.	1.0	0.3	1.3
J-1-7	9.2	Neg.	0.2	0.3	1.5
J-1-8	10.5	0.1	0.2	0.4	3.1
J-1-9	8.4	0.1	0.4	0.8	5.7
J-1-10	10.3	0.1	0.4	0.8	3.7
J-1-11	9.1	Neg.	0.1	0.3	2.2
J-1-12	6.2	Neg.	0.3	0.5	2.3
J-1-13	5.3	Neg.	Neg.	Neg.	4.1
J-1-14	6.4	0.1	0.7	2.0	10.6
J-1-15	4.0	Neg.	0.3	0.7	4.6
J-1-16	2.2	0.1	0.8	1.7	11.9
J-1-17	6.0	0.1	1.3	2.9	9.5
J-1-18	3.0	0.1	0.5	1.1	4.1
J-1-19	4.4	0.2	1.2	2.6	8.3
J-1-20	2.5	Neg.	0.5	1.1	6.6
J-1-21	5.1	1.6	3.0	4.9	16.5
J-1-22	2.1	0.1	0.9	1.8	11.5
J-1-23	3.7	5.4	8.5	12.0	12.5
J-1-24	4.0	0.2	1.2	2.6	12.5
J-1-25	5.9	0.2	1.1	2.4	9.4
J-1-26	5.9	0.1	0.9	1.8	11.9
J-1-27	6.7	0.1	0.6	1.2	8.7
J-1-28	4.8	0.1	0.4	0.8	5.5
J-1-29	2.7	0.3	1.4	2.8	9.0
J-1-30	2.4	0.3	1.6	3.4	26.2
J-1-31	3.8	1.9	3.3	5.2	10.2
J-1-32	4.9	0.1	0.2	0.2	6.7
J-1-33	2.6	48.6	49.7	51.0	8.6
J-1-34	1.9	0.3	2.2	4.8	7.5
J-1-35	2.0	0.3	1.8	3.7	15.4
J-1-36	2.1	0.3	1.6	3.4	17.2
J-1-37	2.5	0.2	1.5	3.2	6.3
J-1-38	0.7	7.9	13.3	20.5	0.3
J-1-39	7.8	Neg.	0.2	0.4	12.3
J-1-40	2.8	0.2	1.2	2.5	14.0

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE for Essex County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-2-1	12.4	0.1	0.2	0.3	3.6
J-2-2	4.5	0.3	0.5	0.6	4.7
J-2-3	11.5	0.1	0.2	0.4	3.7
J-2-4	2.8	0.5	0.9	1.3	6.6
J-2-5	3.8	0.4	0.9	1.5	9.7
J-2-6	2.7	0.6	1.0	1.6	10.1
J-2-7	3.4	0.5	1.0	1.9	14.4
J-2-8	14.0	0.1	0.2	0.3	4.4
J-2-9	8.4	0.2	0.2	0.3	5.0
J-2-10	2.3	0.7	1.5	2.6	10.0
J-2-11	2.7	0.6	1.4	2.4	14.4
J-2-12	2.9	1.1	2.0	3.1	17.6
J-2-13	1.7	2.8	4.3	6.2	20.6
J-2-14	3.5	1.0	1.7	2.6	10.3
J-2-15	2.3	0.7	2.2	4.1	10.5
J-2-16	2.2	0.9	2.8	5.4	23.0
J-2-17	2.4	1.5	3.2	5.5	18.2
J-2-18	1.6	1.1	4.3	8.4	21.7
J-2-19	1.2	1.4	4.1	7.6	20.8
J-2-20	1.1	1.4	3.6	6.5	7.5
J-2-21	2.2	0.5	1.0	1.6	6.9
J-2-22	1.5	2.9	5.6	9.0	20.7
J-2-23	1.1	1.6	4.8	8.9	38.4
J-2-24	1.0	1.7	5.3	10.0	18.5
J-2-25	1.0	1.5	3.8	6.8	19.0
J-2-26	1.6	3.1	5.1	7.6	25.1
J-2-27	1.5	32.8	34.3	36.3	16.5
J-2-28	1.5	6.7	7.6	8.8	10.1
J-2-29	1.5	1.2	3.6	6.7	25.9
J-2-30	0.9	1.8	5.4	9.9	20.3
J-2-31	0.9	1.9	5.9	11.0	35.2
J-2-32	5.6	0.3	0.4	0.7	5.6
J-2-33	4.8	0.3	0.4	0.5	4.7
J-2-34	3.0	0.5	1.1	1.8	8.0
J-2-35	1.4	1.2	3.1	5.6	26.0
J-2-36	1.8	0.9	2.3	4.1	11.8
J-2-37	1.5	1.9	2.8	4.0	26.6
J-2-38	4.1	1.6	1.9	2.4	16.5
J-2-39	2.5	1.6	1.9	2.4	11.2

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Hudson County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-3-1	2.6	1.0	2.5	4.5	9.3
J-3-2	1.1	1.3	8.2	17.1	18.6
J-3-3	6.1	0.2	1.2	2.5	14.0
J-3-4	0.9	3.0	12.7	25.2	29.7
J-3-5	1.5	0.9	3.3	6.5	26.5
J-3-6	0.5	2.7	17.1	35.7	14.8
J-3-7	0.7	1.9	7.8	15.2	39.6
J-3-8	0.5	2.8	17.6	51.5	38.8
J-3-9	1.9	59.2	61.6	64.5	7.1
J-3-10	1.4	1.1	7.0	14.6	21.9
J-3-11	0.7	1.9	15.7	47.2	13.6
J-3-12	0.5	9.1	18.2	29.9	18.8
J-3-13	0.6	2.9	23.3	49.5	34.7
J-3-14	0.9	2.8	13.6	27.6	15.2
J-3-15	1.2	6.0	9.7	18.2	6.9
J-3-16	3.3	26.6	26.9	27.2	16.6
J-3-17	1.0	1.3	5.0	9.7	21.9
J-3-18	1.1	1.5	15.6	33.6	29.0
J-3-19	2.0	2.3	4.5	7.3	5.6
J-3-20	0.7	4.1	8.9	15.2	10.0
J-3-21	1.4	1.1	7.2	21.0	19.6
J-3-22	2.2	1.1	2.9	5.2	3.2
J-3-23	2.6	0.6	4.0	8.3	8.8
J-3-24	1.2	2.8	6.6	11.5	9.1
J-3-25	1.5	13.0	16.0	19.9	5.2
J-3-26	2.5	1.6	5.2	9.9	11.9
J-3-27	4.1	0.8	0.9	1.2	4.5
J-3-28	1.3	7.1	13.3	21.3	25.3

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Middlesex County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-4-1	9.0	0.1	0.6	1.1	1.7
J-4-2	8.2	0.1	0.5	1.1	1.5
J-4-3	11.8	Neg.	0.2	0.3	0.9
J-4-4	4.0	Neg.	1.0	2.1	4.6
J-4-5	6.5	0.1	0.7	1.5	5.8
J-4-6	5.1	0.1	0.8	1.8	4.9
J-4-7	2.0	1.0	2.8	5.1	4.5
J-4-8	1.6	1.7	3.8	6.5	2.7
J-4-9	3.5	49.5	50.7	52.3	64.4
J-4-10	0.8	17.5	21.0	25.5	2.0
J-4-11	4.8	1.0	1.5	2.2	0.9
J-4-12	9.4	Neg.	0.4	0.8	1.3
J-4-13	5.1	0.1	0.5	1.0	1.0
J-4-14	4.6	0.1	0.9	2.0	3.3
J-4-15	4.1	0.1	1.0	2.2	3.8
J-4-16	10.0	0.1	0.5	1.0	4.3
J-4-17	4.5	1.0	1.9	3.1	4.2
J-4-18	1.6	27.5	31.9	37.6	133.6
J-4-19	1.8	5.1	9.2	14.5	7.5
J-4-20	1.3	0.7	4.4	9.2	5.4
J-4-21	2.4	0.7	3.8	7.8	5.0
J-4-22	2.8	0.2	1.6	3.3	5.0
J-4-23	13.4	Neg.	0.2	0.3	1.9
J-4-24	41.4	Neg.	0.1	0.1	1.2
J-4-25	11.7	Neg.	0.2	0.3	2.2
J-4-26	13.1	Neg.	0.1	0.3	1.9
J-4-27	19.9	0.1	0.3	0.5	0.9
J-4-28	8.1	0.1	0.5	1.1	2.5
J-4-29	6.2	1.5	2.3	3.3	2.2
J-4-30	7.3	18.1	19.0	20.2	2.0
J-4-31	3.8	6.7	7.5	8.6	5.9
J-4-32	2.9	Neg.	1.1	2.5	6.5
J-4-33	44.0	Neg.	Neg.	Neg.	1.2
J-4-34	44.4	Neg.	Neg.	Neg.	1.1

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Monmouth County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-5-1	7.7	0.2	0.4	0.7	1.9
J-5-2	9.8	0.2	0.5	0.8	1.9
J-5-3	25.2	0.6	0.2	0.3	1.1
J-5-4	30.2	0.5	0.1	0.2	1.3
J-5-5	17.9	0.1	0.1	0.2	0.8
J-5-6	15.3	0.1	0.2	0.3	1.2
J-5-7	14.4	0.1	0.3	0.5	1.2
J-5-8	32.7	Neg.	0.1	0.1	1.3
J-5-9	39.3	Neg.	Neg.	Neg.	1.1
J-5-10	48.0	Neg.	Neg.	Neg.	1.1
J-5-11	40.0	0.1	0.1	0.2	1.1
J-5-12	31.6	Neg.	0.1	0.1	0.3
J-5-13	26.1	0.1	0.2	0.3	1.2
J-5-14	5.1	0.3	0.7	1.3	1.7
J-5-15	16.2	Neg.	0.1	0.3	1.5
J-5-16	8.9	Neg.	0.3	0.6	1.9
J-5-17	3.5	0.4	1.4	2.7	4.2
J-5-18	63.7	Neg.	Neg.	0.1	1.1
J-5-19	31.0	Neg.	0.1	0.1	0.9
J-5-20	4.3	0.3	0.7	1.1	1.5
J-5-21	3.5	Neg.	0.4	0.8	1.4

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Morris County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2 Min	Avg	Max	Carbon Monoxide, tons/day per mi^2
J-6-1	44.3	Neg.	Neg.	Neg.	1.0
J-6-2	37.1	Neg.	Neg.	0.1	1.0
J-6-3	21.5	0.1	0.2	0.4	1.0
J-6-4	15.7	Neg.	0.1	0.3	0.8
J-6-5	10.2	Neg.	0.2	0.4	0.6
J-6-6	18.3	Neg.	Neg.	0.1	0.9
J-6-7	7.6	Neg.	Neg	0.1	1.2
J-6-8	4.3	0.1	1.0	3.0	2.3
J-6-9	9.3	Neg.	0.3	0.6	1.8
J-6-10	4.0	Neg.	0.4	0.9	1.7
J-6-11	4.6	Neg.	0.4	0.9	2.4
J-6-12	14.4	Neg.	0.4	0.8	1.5
J-6-13	10.1	Neg.	Neg.	0.1	1.6
J-6-14	10.8	1.5	2.0	2.1	1.2
J-6-15	8.4	Neg.	0.1	0.4	1.0
J-6-16	7.2	Neg.	0.2	0.4	1.3
J-6-17	16.3	Neg.	0.1	0.2	0.7
J-6-18	24.0	Neg.	0.1	0.2	0.7
J-6-19	9.4	Neg.	0.2	0.4	0.9
J-6-20	9.7	0.1	0.5	1.1	1.1
J-6-21	15.7	Neg.	0.3	0.6	1.1
J-6-22	7.3	Neg.	Neg.	0.1	0.7
J-6-23	31.6	Neg.	0.1	0.1	1.0
J-6-24	45.1	Neg.	Neg.	0.1	1.0
J-6-25	28.7	Neg.	0.1	0.1	1.0
J-6-26	6.7	Neg.	0.2	0.5	1.0
J-6-27	16.7	Neg.	0.1	0.2	0.4
J-6-28	16.5	Neg.	0.1	0.2	0.3

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Passaic County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2 Min	Avg	Max	Carbon Monoxide, tons/day per mi^2
J-7-1	78.5	Neg.	Neg.	Neg.	1.1
J-7-2	27.3	Neg.	Neg.	0.1	2.4
J-7-3	17.3	Neg.	0.1	0.3	2.4
J-7-4	3.5	0.2	0.6	1.2	2.5
J-7-5	12.6	Neg.	0.2	0.3	2.6
J-7-6	11.3	0.1	0.3	0.5	2.4
J-7-7	3.4	Neg.	0.4	0.9	1.6
J-7-8	3.6	0.4	1.3	2.5	3.9
J-7-9	1.7	1.1	2.9	5.3	3.7
J-7-10	3.9	0.2	0.8	1.7	5.7
J-7-11	3.0	0.2	0.7	1.3	5.3
J-7-12	2.8	0.3	0.7	1.3	4.3
J-7-13	1.4	0.4	2.7	5.6	4.7
J-7-14	0.4	1.4	11.0	23.3	10.0
J-7-15	0.5	5.4	11.3	19.0	7.0
J-7-16	1.6	1.0	3.5	6.8	7.1
J-7-17	1.0	1.2	6.6	13.6	7.2
J-7-18	0.9	1.2	4.4	8.5	11.9
J-7-19	1.0	1.6	5.0	9.2	6.0
J-7-20	1.8	0.6	2.7	5.3	6.6
J-7-21	2.9	2.7	3.9	5.4	12.6
J-7-22	1.8	2.9	4.4	6.4	9.4
J-7-23	3.8	0.2	1.0	2.1	8.6
J-7-24	2.7	2.9	3.6	5.5	13.6
J-7-25	2.0	1.1	3.5	6.6	6.8
J-7-26	1.1	2.4	6.0	10.7	12.3

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Somerset County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-8-1	13.1	Neg.	0.1	0.3	0.3
J-8-2	37.6	Neg.	Neg.	0.1	0.6
J-8-3	5.8	Neg.	Neg.	0.1	0.3
J-8-4	21.7	Neg.	0.1	0.2	0.3
J-8-5	20.2	Neg.	Neg.	Neg	0.6
J-8-6	14.9	Neg.	Neg.	0.1	0.5
J-8-7	19.1	Neg.	Neg.	0.1	0.6
J-8-8	19.3	Neg.	0.1	0.2	0.2
J-8-9	10.9	Neg.	0.2	0.3	1.2
J-8-10	2.9	0.3	1.5	3.1	2.7
J-8-11	10.2	2.3	3.0	3.9	1.9
J-8-12	2.5	0.4	1.7	3.4	2.2
J-8-13	34.1	Neg.	Neg.	0.1	0.6
J-8-14	20.6	Neg.	0.9	0.2	0.6
J-8-15	2.5	3.8	5.8	8.4	1.0
J-8-16	10.1	Neg.	Neg.	Neg.	0.2
J-8-17	9.0	Neg.	0.2	0.5	0.5
J-8-18	32.3	Neg.	Neg.	Neg.	0.6
J-8-19	27.3	Neg.	Neg.	Neg.	0.6

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Union County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
J-9-1	10.2	0.1	0.4	0.8	2.2
J-9-2	6.0	0.2	1.5	2.3	3.2
J-9-3	3.0	0.9	3.0	5.7	6.1
J-9-4	2.8	0.4	2.5	5.2	8.1
J-9-5	4.2	0.3	1.4	2.9	7.6
J-9-6	7.0	0.2	0.9	1.9	6.1
J-9-7	5.2	0.2	1.1	2.3	7.4
J-9-8	5.8	0.2	0.3	4.0	2.4
J-9-9	4.1	0.3	2.0	3.5	6.3
J-9-10	4.9	0.2	1.1	2.2	9.8
J-9-11	3.4	0.8	2.5	4.7	15.0
J-9-12	4.2	0.5	1.9	3.6	9.4
J-9-13	4.9	0.8	1.4	2.2	6.9
J-9-14	2.7	0.5	2.6	5.3	8.7
J-9-15	4.5	0.3	1.6	3.3	19.0
J-9-16	2.7	1.0	3.6	6.8	11.8
J-9-17	4.1	2.3	4.2	6.7	11.2
J-9-18	3.0	0.4	2.5	5.2	15.0
J-9-19	2.2	0.6	4.7	10.0	15.2
J-9-20	1.9	1.2	4.9	9.8	13.6
J-9-21	4.3	3.0	4.0	7.5	8.6
J-9-22	1.8	0.7	5.9	12.6	16.0
J-9-23	1.4	4.0	8.4	14.2	3.6
J-9-24	7.7	27.5	29.0	31.0	6.4

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Bronx County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2 Min	 Avg	 Max	Carbon Monoxide tons/day per mi^2
Y-1-1	0.4	0.1	1.1	2.5	2.3
Y-1-2	0.9	0.2	0.8	1.5	4.6
Y-1-3	1.3	Neg.	0.5	0.9	15.4
Y-1-4	0.8	0.4	2.5	5.3	17.9
Y-1-5	1.1	0.9	4.8	9.9	9.5
Y-1-6	0.2	0.9	3.2	6.1	24.0
Y-1-7	1.0	0.8	5.3	11.0	19.7
Y-1-8	1.0	0.7	4.1	8.5	13.0
Y-1-9	1.0	1.0	6.8	14.4	16.1
Y-1-10	1.0	0.8	4.1	8.3	10.6
Y-1-11	1.0	0.2	1.8	3.7	8.6
Y-1-12	2.0	Neg.	0.1	0.2	6.6
Y-1-13	0.6	2.9	17.3	35.7	14.2
Y-1-14	1.0	2.6	13.5	27.5	9.4
Y-1-15	1.0	0.9	5.1	10.5	17.0
Y-1-16	1.0	1.5	4.7	8.8	8.5
Y-1-17	1.0	0.1	0.9	2.0	13.1
Y-1-18	1.0	Neg.	Neg.	0.1	0.5
Y-1-19	1.0	0.2	1.0	2.0	3.0
Y-1-20	0.2	2.3	9.9	19.7	25.0
Y-1-21	1.0	3.8	21.4	44.1	21.8
Y-1-22	1.0	2.4	14.2	29.4	14.6
Y-1-23	1.0	0.5	3.5	7.2	21.3
Y-1-24	1.0	0.5	5.2	11.4	12.5
Y-1-25	1.0	0.5	2.1	4.2	13.7
Y-1-26	0.7	3.6	19.6	40.2	19.1
Y-1-27	1.0	3.4	17.7	36.0	26.6
Y-1-28	1.0	2.3	12.1	24.7	22.1
Y-1-29	1.0	1.0	5.8	12.0	17.5
Y-1-30	1.0	1.8	9.5	19.3	10.2
Y-1-31	1.0	0.5	2.4	4.9	19.2
Y-1-32	0.5	0.3	1.1	2.2	14.4
Y-1-34	0.8	2.2	12.6	26.0	29.1
Y-1-35	1.0	2.6	13.8	28.4	13.0
Y-1-36	1.0	2.3	13.5	27.9	22.0
Y-1-37	1.0	1.0	6.1	12.8	18.3
Y-1-38	1.0	0.7	2.3	4.3	14.7
Y-1-39	1.0	0.3	1.1	2.3	16.5
Y-1-40	1.1	0.3	1.5	3.1	26.6
Y-1-41	0.8	2.5	10.9	21.8	31.1
Y-1-42	1.0	2.4	12.9	26.5	18.4
Y-1-43	1.0	1.5	7.8	16.0	14.6
Y-1-44	0.9	0.5	7.8	17.2	2.7
Y-1-45	1.6	0.1	0.7	1.4	1.4
Y-1-47	0.6	104.2	106.5	109.5	6.2
Y-1-48	0.9	Neg.	Neg.	0.1	0.6

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Brooklyn

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-2-1	0.2	3.1	7.7	13.7	6.5
Y-2-2	0.3	4.9	9.8	16.1	5.0
Y-2-3	0.4	2.7	8.1	15.0	9.0
y-2-4	1.0	2.2	9.2	18.2	16.8
Y-2-5	0.4	4.4	13.1	24.2	9.3
Y-2-6	0.2	763.5	767.1	771.8	28.0
Y-2-7	0.8	17.9	27.4	39.5	10.4
Y-2-8	1.0	1.4	9.6	20.1	24.2
Y-2-9	0.9	4.2	12.6	23.5	6.4
Y-2-10	0.4	2.9	17.3	35.8	30.0
Y-2-11	1.0	1.5	17.3	37.8	26.9
Y-2-12	1.0	1.2	7.5	15.5	20.0
Y-2-13	1.0	2.1	11.1	22.8	18.3
Y-2-14	1.0	1.8	11.1	23.0	9.5
Y-2-15	0.6	1.6	11.4	24.1	2.5
Y-2-16	0.2	0.6	5.0	10.6	2.5
Y-2-17	1.2	1.8	10.0	13.7	13.8
Y-2-18	1.0	2.4	11.0	22.1	20.6
Y-2-19	1.0	2.8	14.3	29.1	18.9
Y-2-20	1.0	1.8	10.8	22.3	14.1
Y-2-21	1.0	1.7	10.6	22.0	15.8
Y-2-22	1.0	1.5	9.3	19.4	19.5
Y-2-23	0.8	0.9	7.0	14.8	16.0
Y-2-24	0.8	0.6	3.7	7.7	19.5
Y-2-25	1.0	2.6	7.4	13.4	21.4
Y-2-26	1.0	1.4	9.4	19.8	21.0
Y-2-27	1.0	1.0	5.7	11.7	16.2
Y-2-28	1.0	1.2	8.5	17.9	13.4
Y-2-29	1.0	1.7	13.5	28.7	11.0
Y-2-30	1.0	2.6	15.9	33.0	14.8
Y-2-31	1.0	1.4	9.3	19.5	22.8
Y-2-32	1.2	0.9	5.2	10.8	69.0
Y-2-33	0.5	4.4	17.9	35.2	15.8
Y-2-34	1.0	1.3	7.5	15.4	12.3
Y-2-35	1.0	0.6	3.4	7.1	13.3
Y-2-36	1.0	1.5	10.3	21.5	14.7
Y-2-37	1.0	1.2	12.2	26.4	12.9
Y-2-38	1.0	1.0	7.2	16.0	14.9
Y-2-39	1.0	1.2	6.8	13.9	11.1
Y-2-40	1.0	0.4	2.9	6.2	6.6
Y-2-41	1.0	Neg.	Neg.	0.1	8.8
Y-2-42	0.2	2.1	7.6	14.7	35.0
Y-2-43	1.0	1.7	10.2	21.1	11.3
Y-2-44	1.0	1.7	10.7	22.3	7.0
Y-2-45	1.0	1.7	10.0	20.7	10.1
Y-2-46	1.0	1.3	8.8	18.4	13.0
Y-2-47	1.0	1.0	7.2	15.2	13.3
Y-2-48	1.0	0.7	3.7	7.5	9.3
Y-2-49	1.0	0.4	2.5	5.4	7.9
Y-2-50	1.0	0.2	2.0	4.3	8.0

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
for Brooklyn

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-2-51	1.0	Neg.	0.1	0.2	13.4
Y-2-52	0.5	1.0	4.9	10.1	23.0
Y-2-53	1.0	1.1	9.9	21.3	10.2
Y-2-54	1.0	1.2	7.7	16.1	10.6
Y-2-55	1.0	1.2	7.5	15.6	9.7
Y-2-56	1.0	0.7	5.4	11.5	15.8
Y-2-57	1.0	0.7	6.1	13.1	13.1
Y-2-58	1.0	0.5	4.4	9.5	15.9
Y-2-59	2.0	0.2	0.9	1.7	10.7
Y-2-60	1.0	Neg.	Neg.	Neg.	11.1
Y-2-61	0.2	0.8	14.7	32.7	30.5
Y-2-62	0.9	0.2	2.6	5.6	1.2
Y-2-63	1.0	1.1	8.6	18.2	16.1
Y-2-64	1.0	1.0	7.4	15.7	12.0
Y-2-65	1.0	0.7	7.9	17.2	16.1
Y-2-66	1.0	1.3	9.0	18.8	9.4
Y-2-67	0.5	0.9	5.9	12.4	14.6
Y-2-68	1.0	1.1	6.6	13.7	11.0
Y-2-69	1.0	0.7	5.5	11.8	12.6
Y-2-70	1.0	1.1	9.8	21.1	11.7
Y-2-71	1.0	0.2	2.7	5.9	1.6
Y-2-72	6.5	Neg.	Neg.	Neg.	4.2
Y-2-73	0.5	0.9	8.1	17.4	12.2
Y-2-74	1.0	0.6	4.8	10.1	15.0
Y-2-75	1.0	1.4	9.5	19.9	11.5
Y-2-76	0.8	0.6	6.0	13.0	10.4
Y-2-77	0.8	0.2	1.5	3.2	3.9
Y-2-78	1.0	0.3	4.2	9.1	4.0

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Staten Island

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-3-1	3.5	0.7	1.9	3.5	1.7
Y-3-2	3.6	0.3	1.7	3.4	4.9
Y-3-3	4.1	0.2	1.3	2.7	3.7
Y-3-4	2.2	0.4	2.6	5.5	3.6
Y-3-5	4.3	Neg.	0.1	0.3	.6
Y-3-6	4.0	Neg.	0.5	1.1	2.7
Y-3-7	4.0	0.1	0.4	0.8	2.9
Y-3-8	3.2	0.1	0.5	1.0	2.8
Y-3-9	4.5	8.6	8.7	8.9	.9
Y-3-10	4.0	Neg.	0.2	0.5	1.8
Y-3-11	3.8	0.1	0.7	1.5	3.4
Y-3-12	0.7	0.2	1.0	2.0	2.9
Y-3-13	3.9	Neg.	Neg.	0.1	1.1
Y-3-14	4.0	Neg.	0.1	0.3	1.5
Y-3-15	3.1	Neg.	0.3	0.6	2.5
Y-3-16	0.8	Neg.	0.1	0.2	.9
Y-3-17	0.9	Neg.	0.3	0.6	.9
Y-3-18	3.5	0.1	0.2	0.5	1.0
Y-3-19	1.5	Neg.	0.1	0.2	1.5

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Manhattan

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-4-1	0.8	2.1	10.5	21.4	3.4
Y-4-2	0.3	3.8	14.1	27.4	88.7
Y-4-3	0.4	1.6	6.6	13.1	72.5
Y-4-4	0.7	64.9	78.9	97.0	31.9
Y-4-5	0.7	3.3	21.4	44.7	23.0
Y-4-6	0.2	2.2	9.7	19.4	43.0
Y-4-7	0.2	1.6	5.1	9.7	52.0
Y-4-8	1.0	2.7	11.9	23.7	39.0
Y-4-9	0.6	6.3	36.2	74.6	49.3
Y-4-10	1.1	3.9	21.8	44.8	37.4
Y-4-11	0.2	1.2	5.3	10.5	58.0
Y-4-12	1.0	5.9	25.6	51.0	36.9
Y-4-13	1.0	3.7	18.7	38.0	19.1
Y-4-14	0.7	1.8	7.1	13.9	64.4
Y-4-15	0.6	13.7	46.4	88.5	38.8
Y-4-16	1.0	3.5	15.0	29.9	25.6
Y-4-17	0.8	5.2	22.3	44.3	33.0
Y-4-18	0.4	.1	1.0	2.1	55.3
Y-4-19	0.2	8.9	20.3	35.0	153.5
Y-4-20	1.0	39.6	55.1	75.2	42.9
Y-4-21	1.0	4.0	19.0	38.4	43.7
Y-4-22	0.4	78.0	111.9	155.6	54.5
Y-4-23	0.7	2.5	11.7	23.6	66.6
Y-4-24	1.0	2.9	17.4	36.0	45.7
Y-4-25	0.8	108.8	125.5	147.00	84.8
Y-4-26	1.0	4.7	18.4	35.9	49.8
Y-4-27	1.1	20.3	42.1	70.2	56.4
Y-4-28	1.0	2.7	9.2	17.7	51.0
Y-4-29	1.1	112.6	129.9	152.1	45.1
Y-4-30	0.2	1.8	18.3	39.5	129.5
Y-4-31	0.8	1.3	7.4	15.2	51.8
Y-4-32	0.4	4.9	21.9	43.7	86.3
Y-4-33	0.4	0.4	4.5	9.7	1.0

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE for Queens County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-5-1	0.8	154.2	159.2	165.6	19.0
Y-5-2	2.2	0.3	1.7	3.6	20.8
Y-5-3	3.2	0.8	3.3	6.7	14.0
Y-5-4	4.6	0.4	2.1	4.4	19.0
Y-5-5	3.8	0.2	1.1	2.3	20.3
Y-5-6	1.3	1.3	7.6	15.6	14.7
Y-5-7	1.0	1.3	7.8	16.1	21.7
Y-5-8	1.0	161.1	166.6	173.6	22.9
Y-5-9	1.0	1.2	6.5	13.2	13.3
Y-5-10	1.0	1.5	8.6	17.9	42.5
Y-5-11	1.0	1.4	8.4	17.3	7.5
Y-5-12	1.0	1.3	7.9	16.3	18.0
Y-5-13	4.0	0.7	4.5	9.5	27.4
Y-5-14	4.0	0.4	3.4	7.2	14.0
Y-5-15	4.0	0.4	3.1	6.6	19.2
Y-5-16	4.6	0.2	3.0	6.6	17.3
Y-5-17	1.0	2.4	8.6	16.5	23.9
Y-5-18	1.0	1.5	7.8	16.0	25.2
Y-5-19	1.0	1.0	5.3	10.8	25.2
Y-5-20	1.0	1.1	7.0	14.6	14.4
Y-5-21	1.0	1.2	6.4	13.2	27.6
Y-5-22	0.6	8.6	21.7	38.6	19.5
Y-5-23	1.0	1.8	5.9	11.1	26.3
Y-5-24	1.0	0.5	2.8	5.7	25.2
Y-5-25	1.0	0.9	5.2	10.7	32.8
Y-5-26	1.0	1.5	9.2	19.1	16.4
Y-5-27	4.0	0.7	5.4	11.4	25.0
Y-5-28	4.0	0.3	2.8	6.0	11.7
Y-5-29	4.5	0.3	2.0	4.3	14.7
Y-5-30	1.1	1.1	5.3	10.8	0.8
Y-5-31	1.0	0.4	2.7	5.7	7.8
Y-5-32	1.0	0.5	3.6	7.6	13.9
Y-5-33	1.0	0.4	2.5	5.2	24.0
Y-5-34	1.7	0.6	3.7	7.7	9.6
Y-5-35	3.0	0.4	3.3	7.0	18.3
Y-5-36	4.0	0.4	2.7	5.7	11.3
Y-5-37	4.0	0.4	2.8	5.9	13.8
Y-5-38	4.1	0.2	1.9	4.0	11.7
Y-5-39	3.5	0.1	0.8	1.7	17.9
Y-5-40	4.9	0.2	1.1	2.2	23.3
Y-5-41	8.0	0.1	0.6	1.4	4.7
Y-5-42	4.6	0.1	1.1	2.2	6.6
Y-5-43	1.8	0.1	0.6	1.3	4.1
Y-5-44	1.6	4.1	5.1	6.4	7.8

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Nassau County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-6-1	5.0	Neg.	0.4	1.0	4.3
Y-6-2	9.0	Neg.	0.1	0.3	2.2
Y-6-3	7.6	2.2	2.3	2.4	2.5
Y-6-4	6.6	0.1	0.3	0.5	1.5
Y-6-5	2.0	Neg.	Neg.	Neg.	1.1
Y-6-6	4.0	Neg.	0.1	0.3	1.8
Y-6-7	4.0	Neg.	Neg.	Neg.	1.0
Y-6-8	8.0	Neg.	Neg.	Neg.	1.4
Y-6-9	3.0	Neg.	0.1	0.3	13.3
Y-6-10	6.0	0.1	0.2	0.4	4.0
Y-6-11	6.0	Neg.	0.2	0.3	8.6
Y-6-12	4.8	Neg.	0.2	0.4	33.7
Y-6-13	2.5	0.2	0.5	0.4	6.1
Y-6-14	3.0	0.2	1.1	1.3	14.6
Y-6-15	2.5	0.1	0.4	0.9	5.6
Y-6-16	7.0	0.1	0.2	0.2	10.6
Y-6-17	5.0	0.3	0.6	1.0	3.4
Y-6-18	13.0	Neg.	0.1	0.2	6.1
Y-6-19	6.5	Neg.	0.2	0.4	12.2
Y-6-20	5.0	Neg.	Neg.	Neg.	3.4
Y-6-21	7.0	0.2	0.5	1.0	9.7
Y-6-22	6.0	Neg.	0.3	0.6	5.2
Y-6-23	7.0	1.7	2.7	3.9	5.6
Y-6-24	2.2	0.3	1.0	2.0	8.0
Y-6-25	5.1	0.5	0.9	1.5	6.2
Y-6-26	3.0	Neg.	0.3	0.6	9.2
Y-6-27	4.0	0.1	0.5	1.8	2.8
Y-6-28	6.0	0.1	0.3	0.7	12.6
Y-6-29	3.2	0.1	0.7	2.9	18.1
Y-6-30	3.8	0.1	0.1	2.1	2.4
Y-6-31	3.8	Neg.	0.4	0.8	10.4
Y-6-32	3.5	0.1	0.6	1.3	7.7
Y-6-33	3.2	0.1	1.3	2.8	6.7
Y-6-34	9.0	Neg.	0.2	0.3	6.7
Y-6-35	5.0	Neg.	0.3	0.6	4.6
Y-6-36	4.0	0.1	0.7	1.4	3.1
Y-6-37	3.6	0.1	0.5	1.1	5.2
Y-6-38	3.7	0.1	0.8	1.8	8.6
Y-6-39	3.1	0.1	0.4	0.9	6.4
Y-6-40	2.2	Neg.	0.2	0.5	8.5
Y-6-41	2.0	Neg.	0.3	0.6	5.9
Y-6-42	3.0	0.1	0.4	0.9	8.8
Y-6-43	3.5	0.1	0.4	0.8	9.1
Y-6-44	4.2	Neg.	0.2	0.5	5.2
Y-6-45	5.0	Neg.	0.1	0.8	7.2
Y-6-46	7.0	Neg.	Neg.	0.1	3.6
Y-6-47	4.0	0.2	0.1	0.2	2.4
Y-6-48	2.1	18.8	18.9	19.0	1.7
Y-6-49	6.2	0.1	1.0	2.3	2.5
Y-6-50	2.1	Neg.	0.3	5.9	3.0
Y-6-51	4.8	Neg.	0.1	0.1	2.9
Y-6-52	4.6	0.5	1.1	1.8	5.4
Y-6-53	4.6	0.2	0.4	0.6	6.0
Y-6-54	3.4	Neg.	0.1	0.3	6.0
Y-6-55	5.0	Neg.	0.2	0.4	8.9
Y-6-56	3.7	Neg.	0.3	0.6	6.2
Y-6-57	5.0	Neg.	0.2	0.8	6.6
Y-6-58	7.5	Neg.	0.2	0.4	5.1
Y-6-59	7.0	Neg.	Neg.	Neg.	1.4
Y-6-60	2.0	Neg.	Neg.	Neg.	1.3

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Rockland County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2			Carbon Monoxide, tons/day per mi^2
		Min	Avg	Max	
Y-7-1	24.3	Neg.	Neg.	Neg.	Neg.
Y-7-2	3.5	5.1	5.1	5.2	4.0
Y-7-3	19.5	Neg.	0.1	0.3	0.3
Y-7-4	3.7	Neg.	0.3	0.8	5.8
Y-7-5	2.9	Neg.	Neg.	Neg.	1.8
Y-7-6	28.1	Neg.	Neg.	Neg.	0.4
Y-7-7	12.5	Neg.	Neg.	Neg.	1.1
Y-7-8	4.1	0.1	0.1	0.2	8.0
Y-7-9	12.7	Neg.	Neg.	0.1	2.5
Y-7-10	13.6	Neg.	Neg.	Neg.	1.0
Y-7-11	13.6	Neg.	Neg.	Neg.	1.2
Y-7-12	13.8	Neg.	Neg.	0.1	2.4
Y-7-13	2.3	Neg.	0.2	0.4	9.3
Y-7-14	6.7	Neg.	0.1	0.1	3.5
Y-7-15	6.7	0.4	0.6	0.8	1.5
Y-7-16	6.7	0.5	0.7	0.8	1.9

EMISSION CONCENTRATIONS OF SULFUR OXIDES AND CARBON MONOXIDE
For Westchester County

Zone	Area, mi^2	Sulfur Oxides, tons/day per mi^2 Min	Avg	Max	Carbon Monoxide, tons/day per mi^2
Y-8-1	6.0	Neg.	0.1	0.2	2.3
Y-8-2	4.5	1.1	1.7	2.4	5.9
Y-8-3	5.7	2.4	2.7	3.2	2.2
Y-8-4	26.2	Neg.	Neg.	Neg.	0.3
Y-8-5	5.2	0.4	0.6	0.7	2.5
Y-8-6	15.0	Neg.	Neg.	0.1	2.1
Y-8-7	28.6	Neg.	Neg.	0.1	1.2
Y-8-8	32.6	Neg.	Neg.	Neg.	1.2
Y-8-9	22.9	Neg.	Neg.	Neg.	1.4
Y-8-10	16.0	Neg.	Neg.	Neg.	1.3
Y-8-11	12.6	Neg.	Neg.	Neg.	0.6
Y-8-12	38.5	Neg.	Neg.	0.1	1.4
Y-8-13	23.3	Neg.	Neg.	Neg.	0.8
Y-8-14	23.6	Neg.	Neg.	0.1	0.3
Y-8-15	2.8	Neg.	0.[illegible]	0.6	4.3
Y-8-16	26.1	Neg.	Neg.	Neg.	1.3
Y-8-17	4.0	0.1	0.9	1.8	9.9
Y-8-18	4.1	Neg.	0.1	0.1	2.6
Y-8-19	9.6	Neg.	0.1	0.2	2.9
Y-8-20	8.2	Neg.	Neg.	0.1	0.6
Y-8-21	6.0	Neg.	0.4	0.9	5.6
Y-8-22	5.2	0.6	1.0	1.5	4.9
Y-8-23	7.3	0.3	0.6	0.9	1.4
Y-8-24	7.2	Neg.	0.1	0.3	5.8
Y-8-25	13.6	0.1	0.2	0.3	2.9
Y-8-26	5.2	0.2	0.8	1.5	9.1
Y-8-27	4.9	0.1	0.7	1.4	3.2
Y-8-28	6.5	Neg.	0.2	0.4	3.7
Y-8-29	10.3	Neg.	Neg.	0.1	1.7
Y-8-30	10.3	Neg.	0.1	0.2	4.6
Y-8-31	2.2	0.7	1.5	2.5	11.6
Y-8-32	5.0	Neg.	0.2	0.5	3.7
Y-8-33	3.3	Neg.	0.4	0.9	10.2
Y-8-34	3.0	0.2	0.6	1.2	6.4
Y-8-35	1.0	0.3	2.0	4.2	18.3
Y-8-36	4.0	0.2	0.6	1.2	4.4
Y-8-37	5.1	0.1	0.5	1.1	5.0
Y-8-38	2.0	0.1	0.8	1.7	7.5
Y-8-39	0.3	18.9	27.9	39.4	56.7
Y-8-40	1.0	1.0	5.9	12.3	45.8
Y-8-41	4.5	0.2	1.2	2.5	10.2
Y-8-42	5.0	0.3	0.8	1.4	7.4
Y-8-43	1.7	1.0	1.7	2.6	8.3
Y-8-44	3.1	Neg.	0.2	0.5	2.9
Y-8-45	4.2	0.2	1.0	2.1	7.1
Y-8-46	3.1	0.2	1.2	2.5	9.7
Y-8-47	2.5	0.4	2.0	4.0	15.0
Y-8-48	1.9	1.0	2.6	4.8	15.9
Y-8-49	2.2	0.1	0.5	0.9	7.5

REFUSE DISPOSAL
(tons/year)

Area	Industrial		Domestic		Comm. and Gov't.		Incineration	Open Burning	Grand Total
	Inc.[a]	O.B.[b]	Inc.	O.B.	Inc.	O.B.			
Bergen	130	-	-	58,786	30,348	-	30,478	58,786	89,264
Essex	222	-	-	17,367	15,255	-	15,477	17,367	32,844
Hudson	400	-	-	-	122,093	-	122,493	-	122,493
Middlesex	2,549	-	-	37,472	17,266	-	19,815	37,472	57,287
Monmouth	-	-	-	38,285	2,003	-	2,003	38,285	40,288
Morris	46	-	-	44,643	5,649	-	5,695	44,643	50,338
Passaic	4,100	-	-	26,129	771	-	4,871	26,129	31,000
Somerset	375	-	-	17,656	492	-	867	17,656	18,523
Union	18,507	-	-	15,035	11,507	-	30,014	15,035	45,049
New Jersey Total	26,329	-	-	255,373	205,384	-	231,713	255,373	487,086
Bronx	-	-	304,300	-	149,508	-	453,808	-	453,808
Brooklyn	-	-	455,187	-	1,032,009	-	1,487,196	-	1,487,196
Staten Island	-	-	25,245	-	-	-	25,245	-	25,245
Manhattan	-	-	425,495	-	743,044	-	1,168,539	-	1,168,539
Queens	-	-	301,759	-	307,579	-	609,338	-	609,338
New York City Total	-	-	1,511,986	-	2,232,140	-	3,744,126	-	3,744,126
Nassau	1,822	1,412	-	-	727,035	74	728,857	1,486	730,343
Rockland	22	3,228	425	1,145	22,897	25,383	23,344	29,756	53,100
Westchester	7,655	3,457	1,954	7,264	238,620	21,506	248,229	32,227	280,456
Outer New York Total	9,499	8,097	2,379	8,409	988,552	46,963	1,000,430	63,469	1,063,899
New York Total	9,499	8,097	1,514,365	8,409	3,220,692	46,963	4,744,556	63,469	4,808,025
Study Area Total	35,828	8,097	1,514,365	263,782	3,426,076	46,963	4,976,269	318,842	5,295,111

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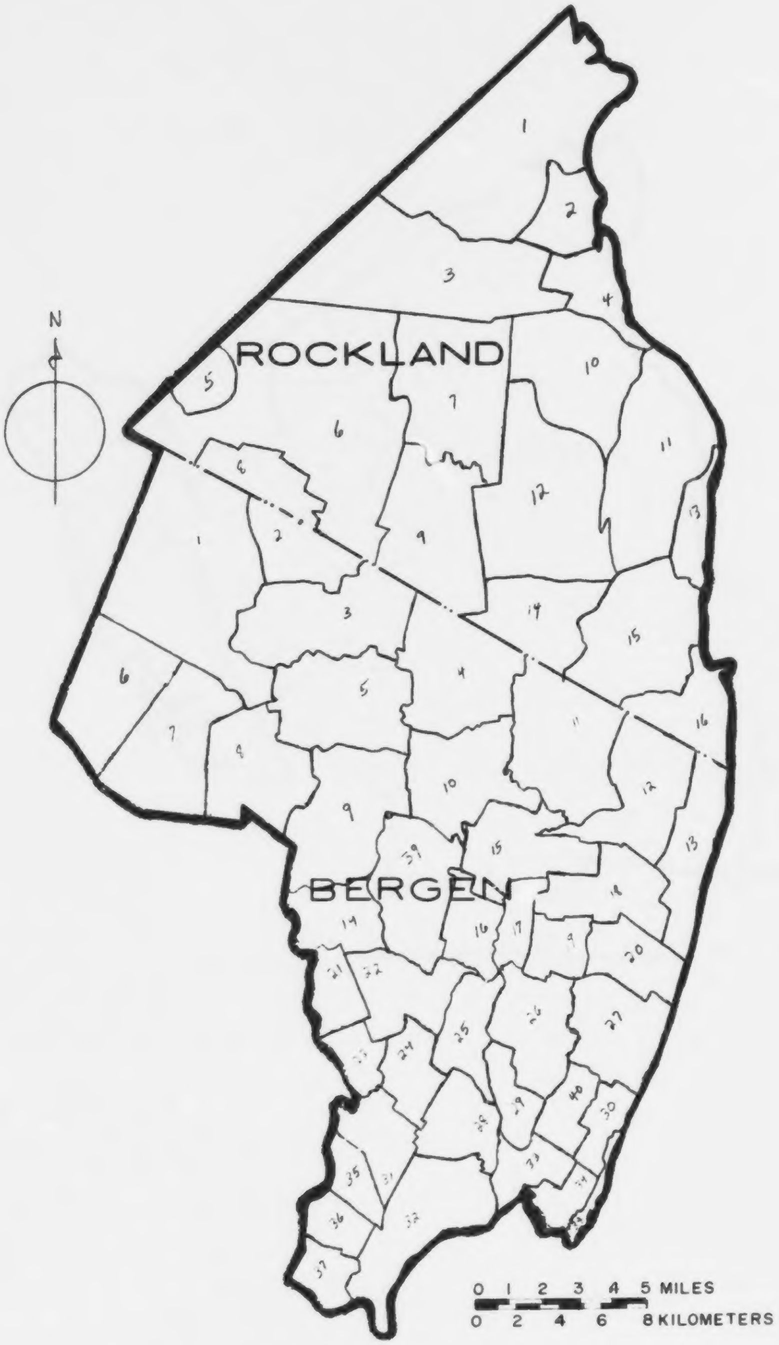
[a] Incineration

[b] Open burning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BERGEN
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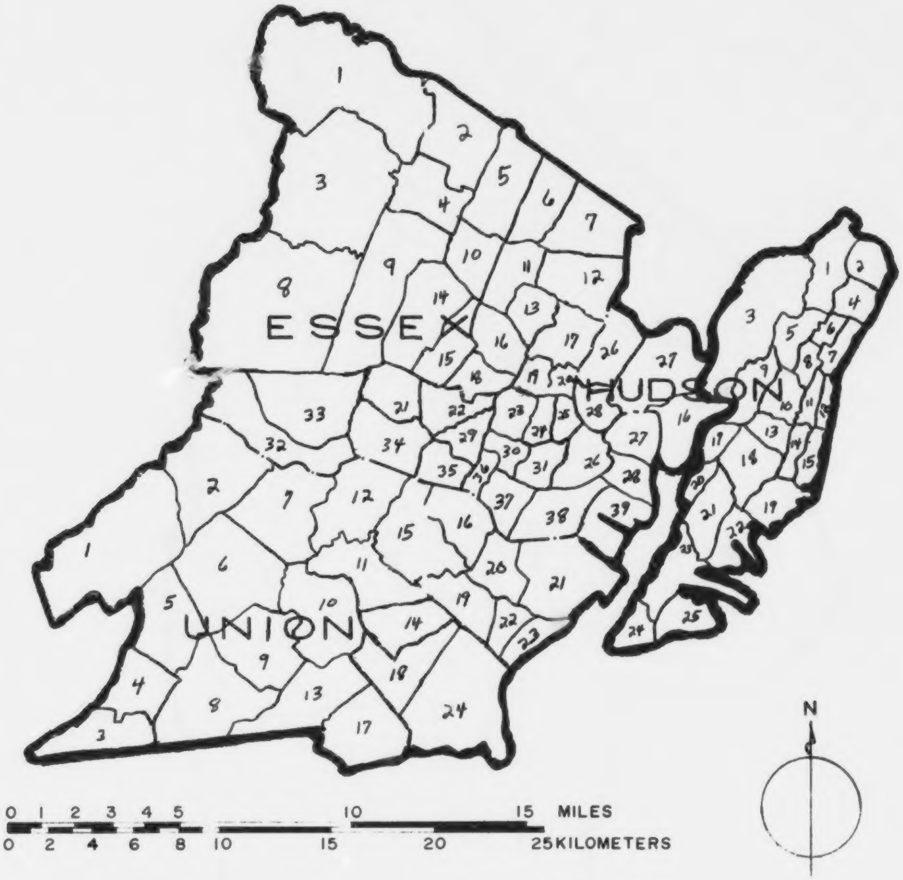
0 2 4 6 8 KILOMETERS

Emission zones for Rockland (Y-7) and Bergen (J-1).


ESSEX
HUDSON
UNION
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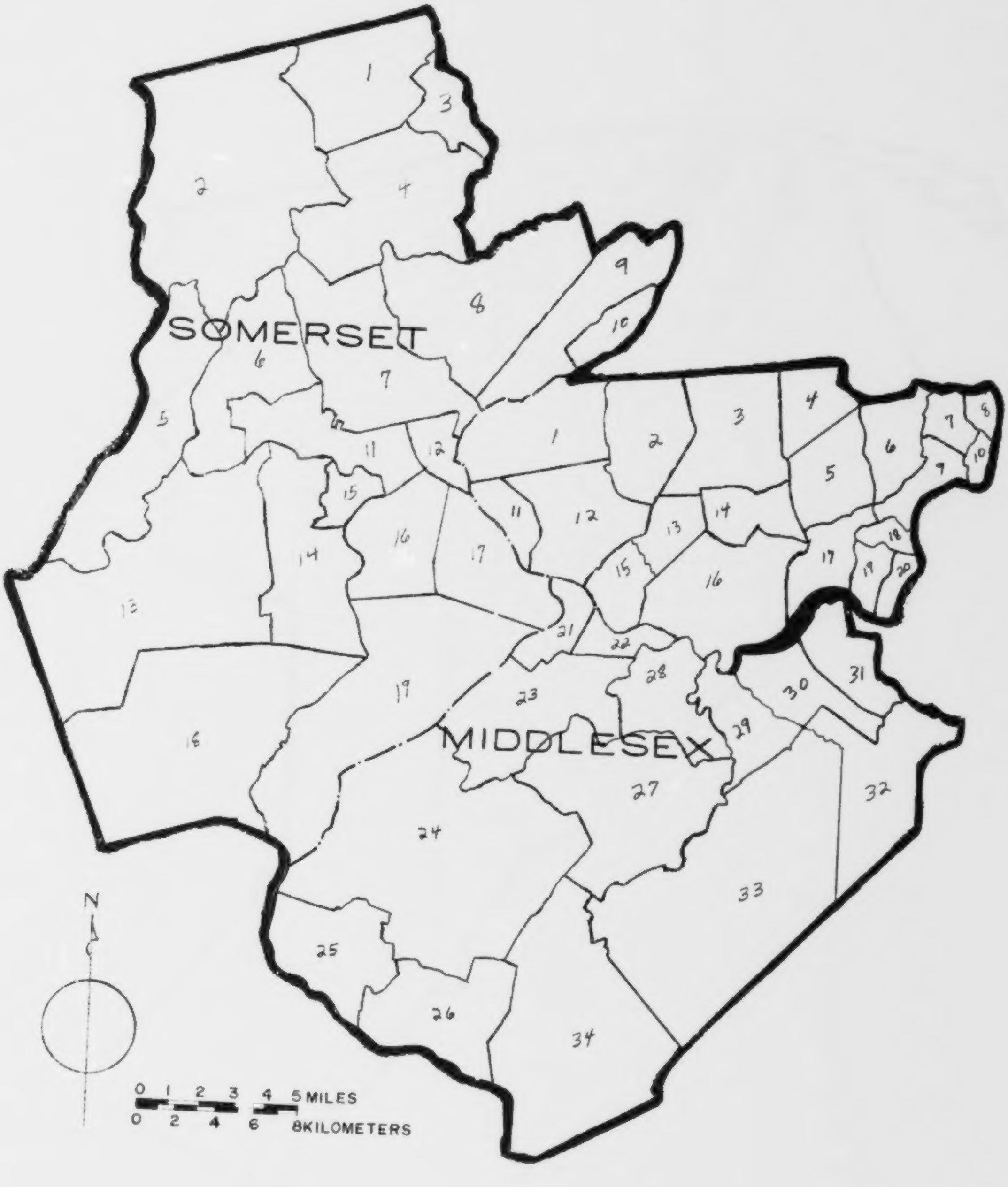
0 2 4 6 8 10 15 20 25 KILOMETERS

Emission zones for Essex (J-2), Hudson (J-3), and Union (J-9).


SOMERSET
MIDDLESEX
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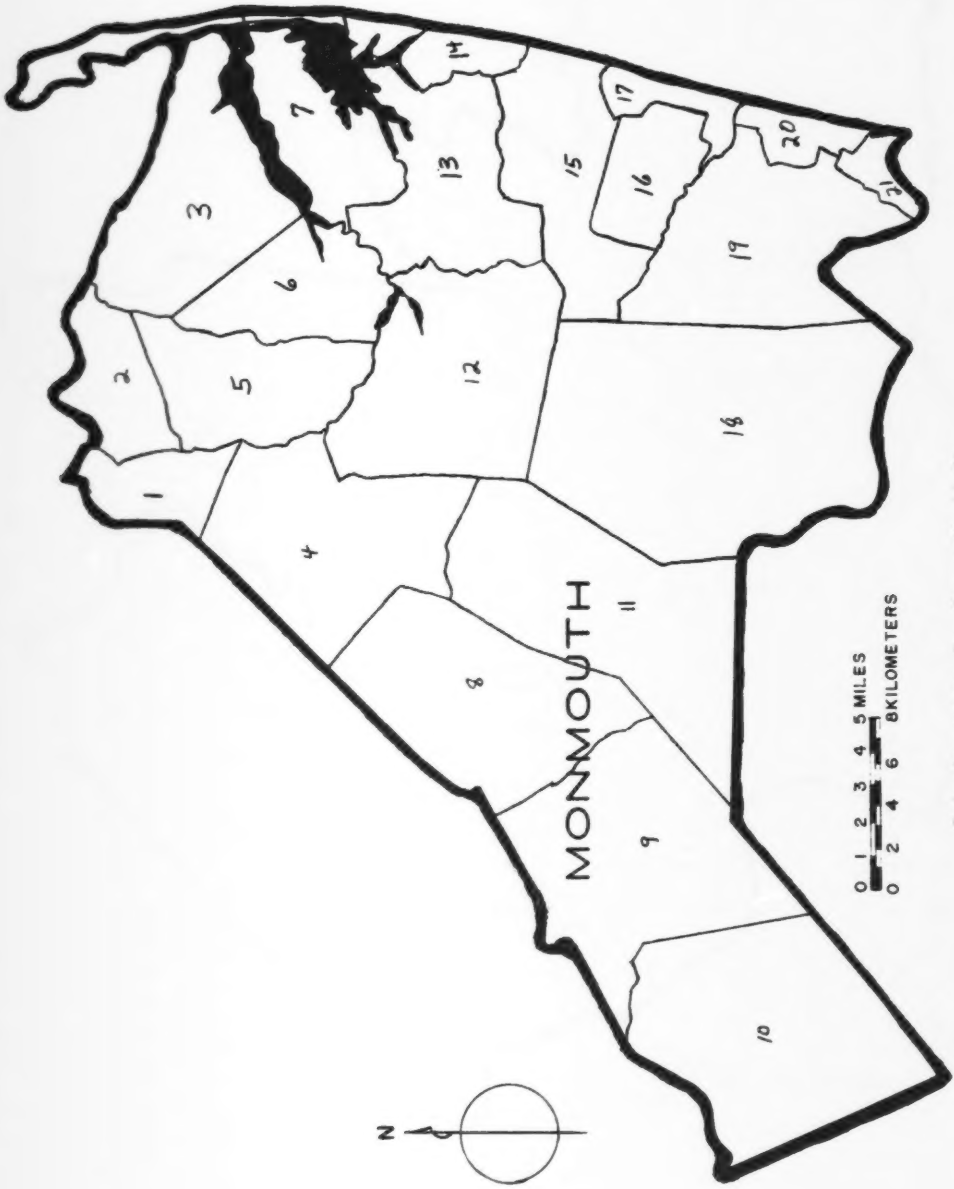
Emission zones for Middlesex (J-4) and Somerset (J-8).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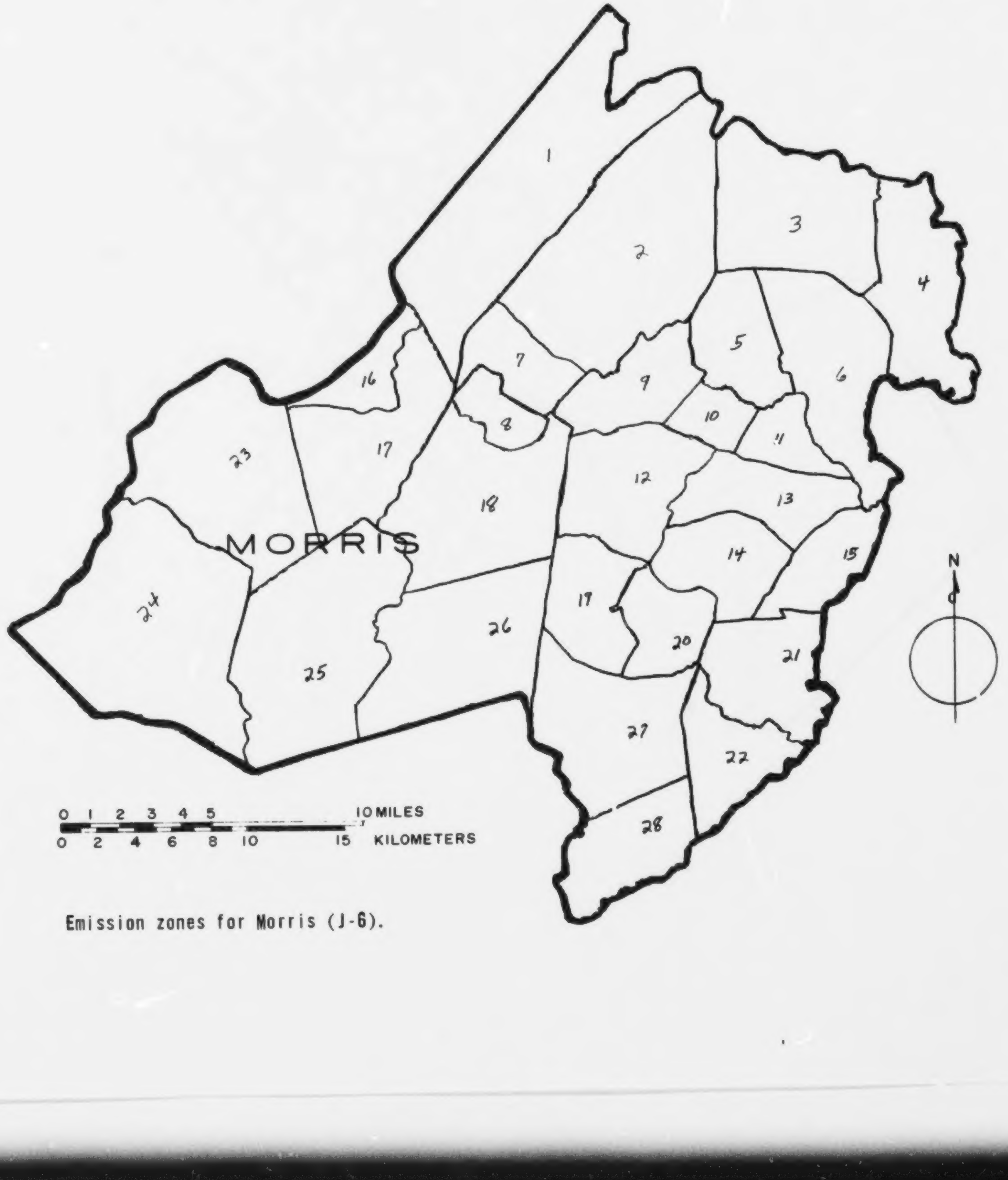
Emission zones for Monmouth (J-5).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MORRIS
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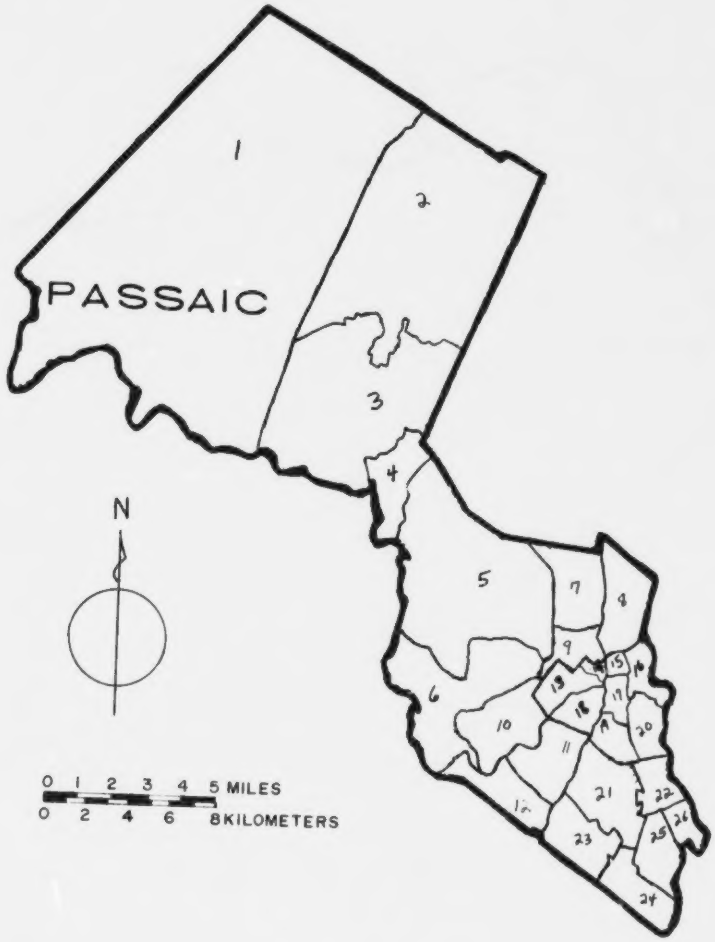
0 2 4 6 8 10 15 KILOMETERS

Emission zones for Morris (J-6).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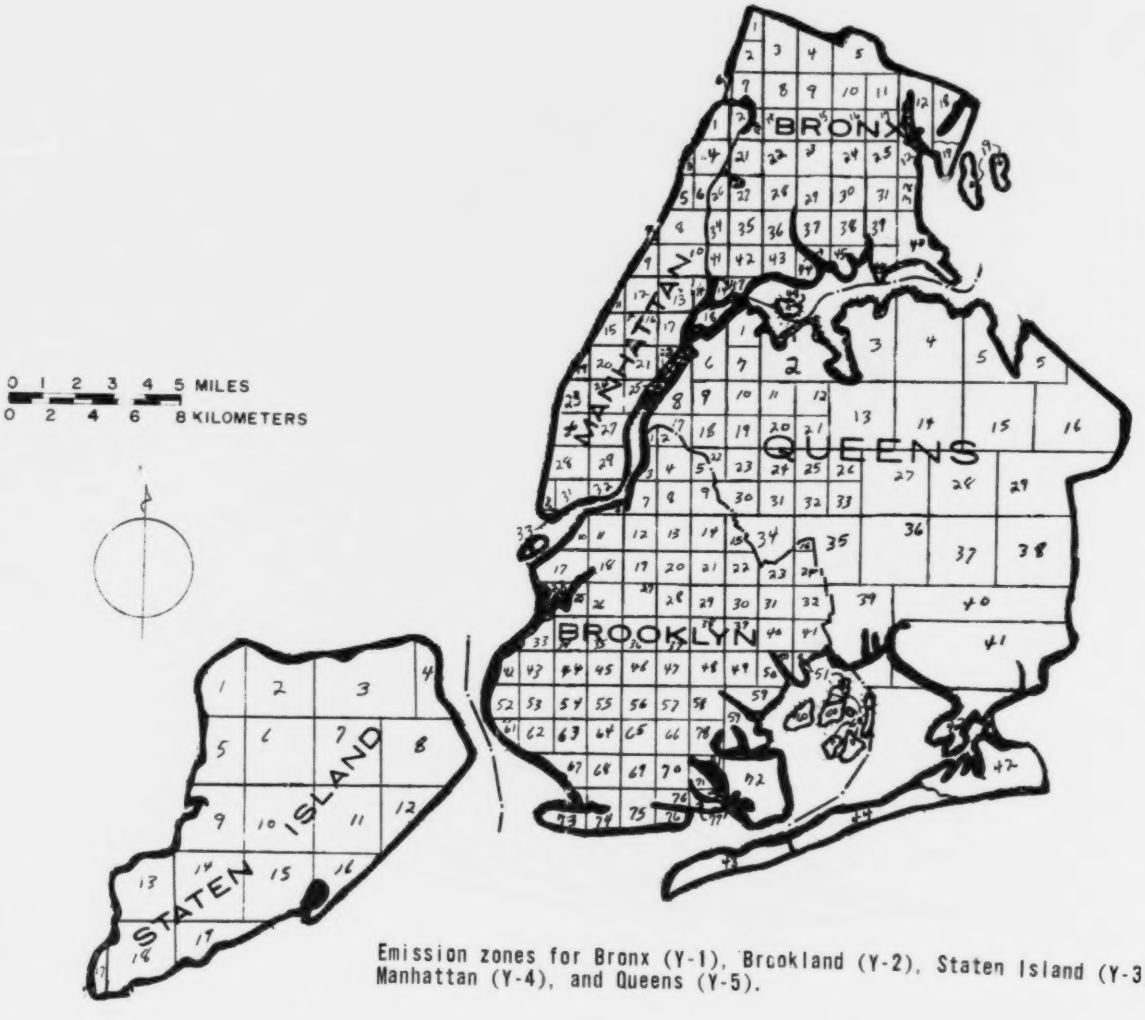
Emission zones for Passaic (J-7).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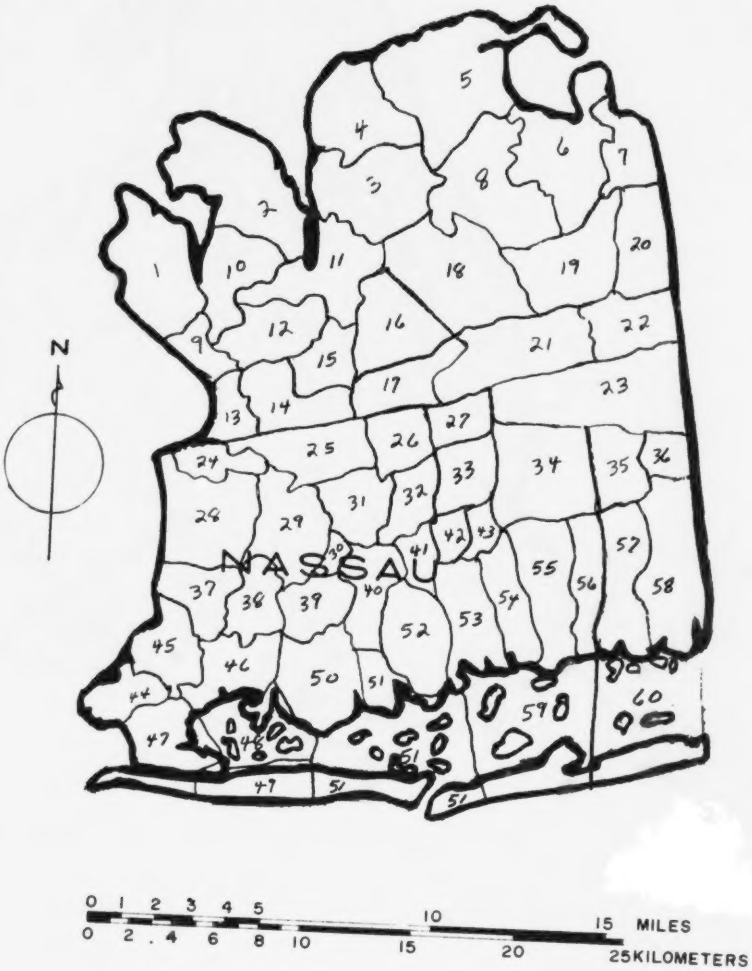
BRONX
MANHATTAN
QUEENS
BROOKLYN
STATEN ISLAND

Emission zones for Bronx (Y-1), Brookland (Y-2), Staten Island (Y-3), Manhattan (Y-4), and Queens (Y-5).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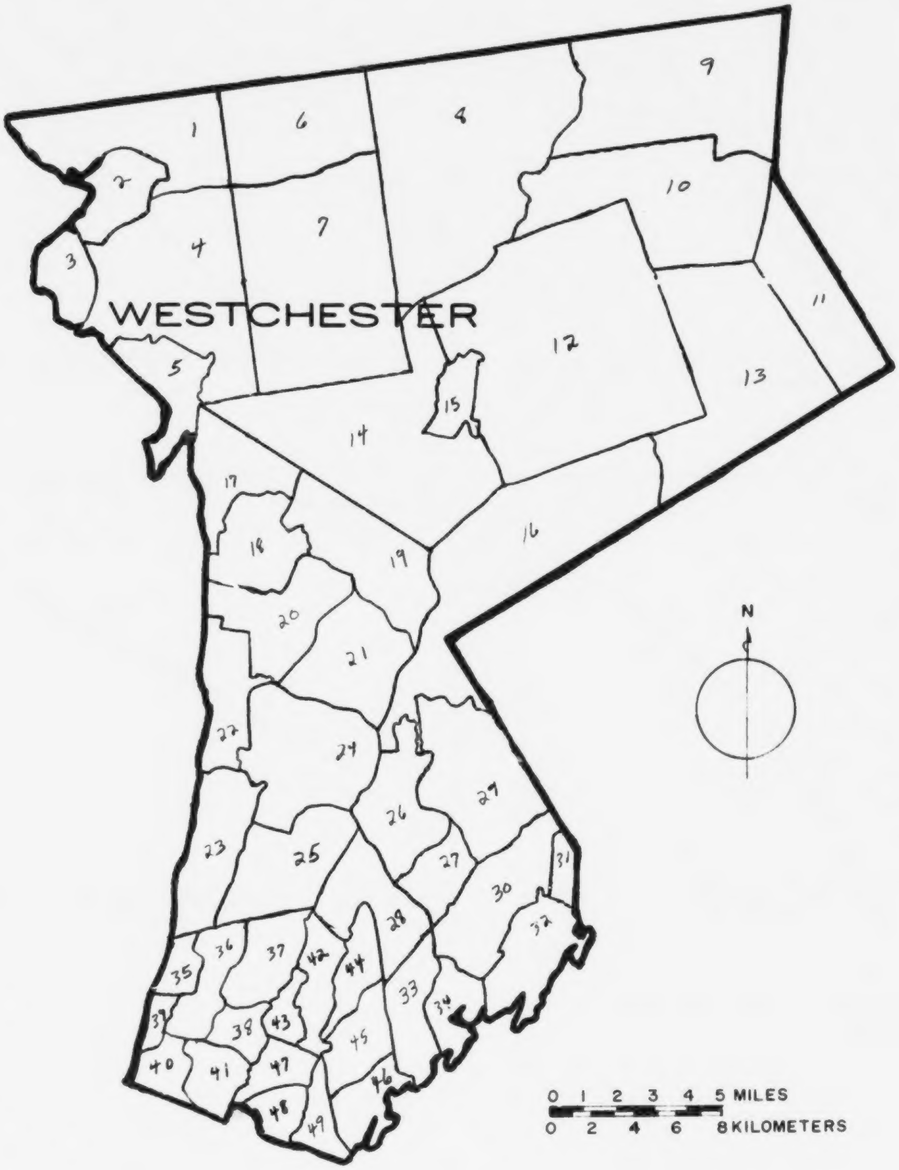
Emission zones for Nassau (Y-6).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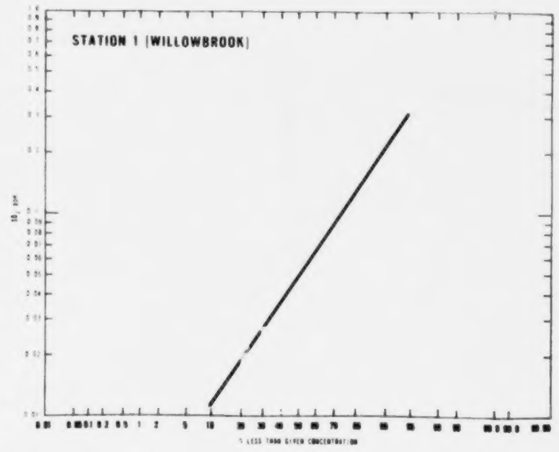
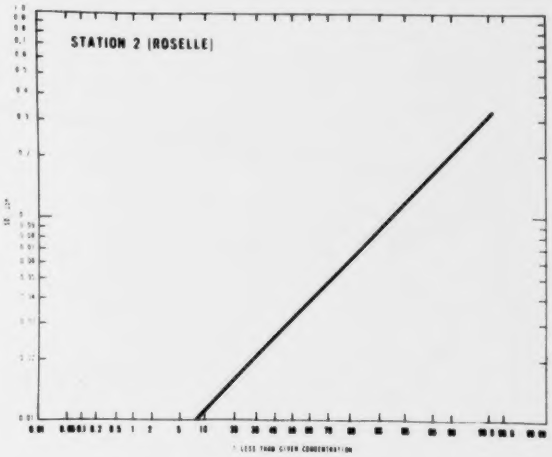
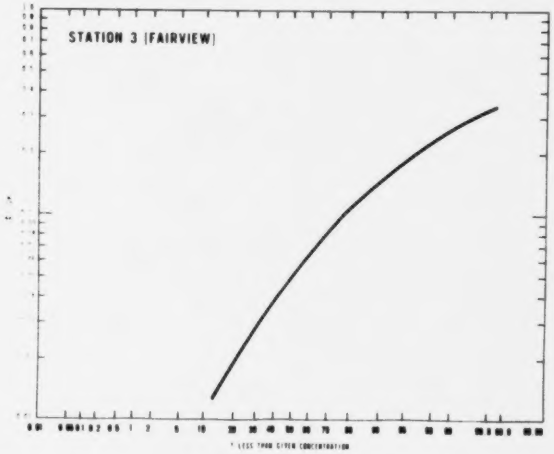
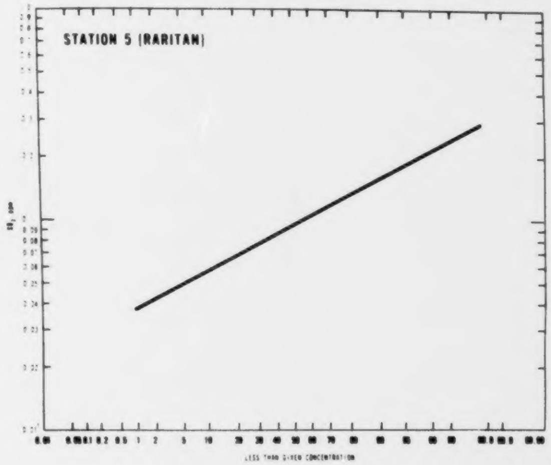
0 1 2 3 4 5 MILES
0 2 4 6 8 KILOMETERS

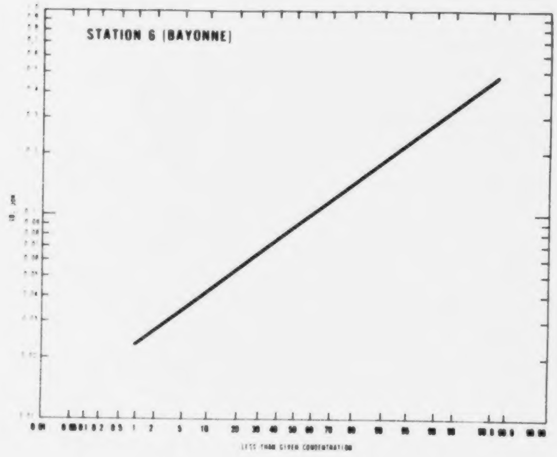
Emission zones for Westchester (Y-8).



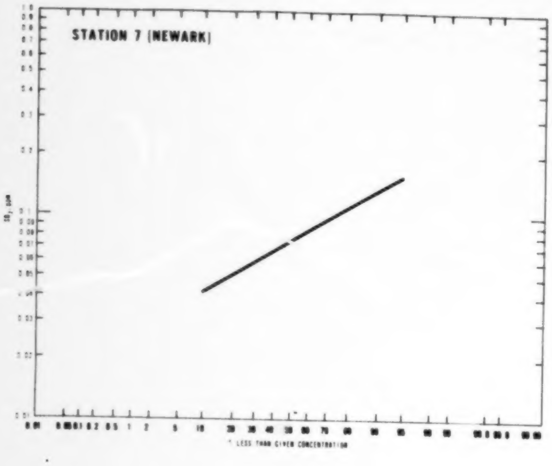


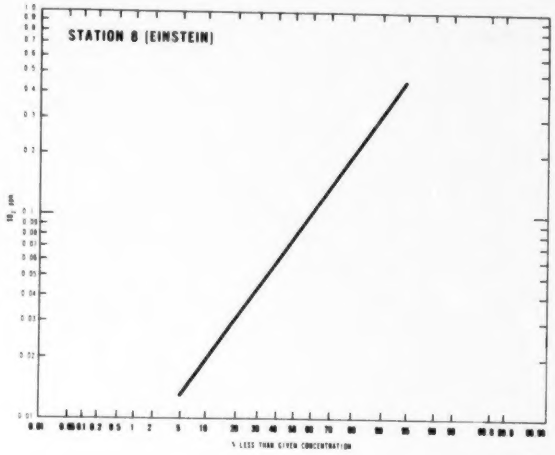


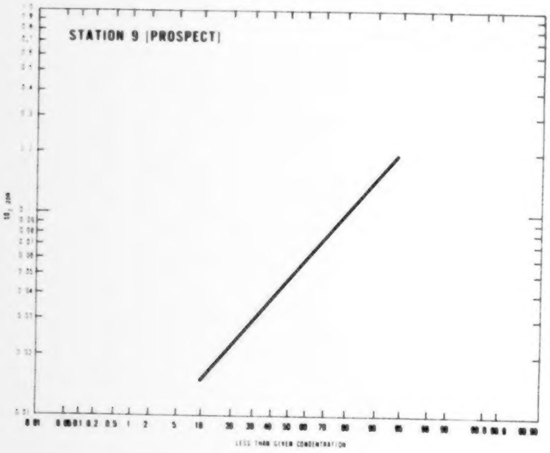


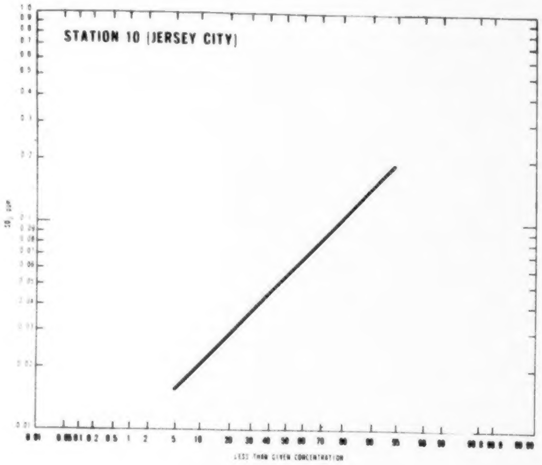


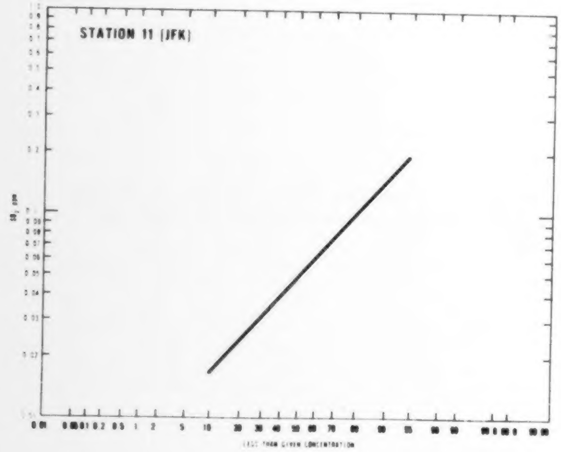
Cumulative frequency distribution of hourly sulfur dioxide concentrations during summer 1966.





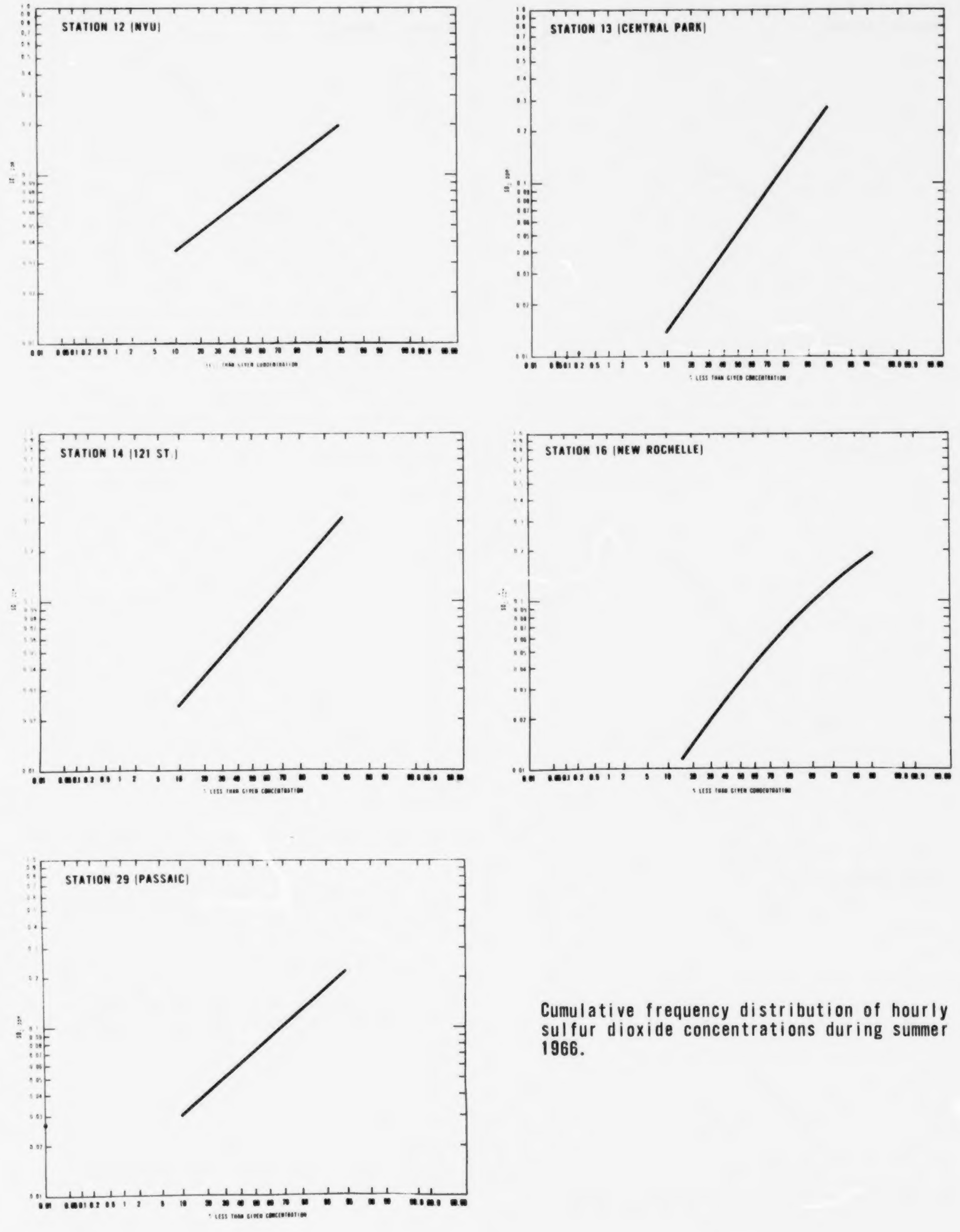




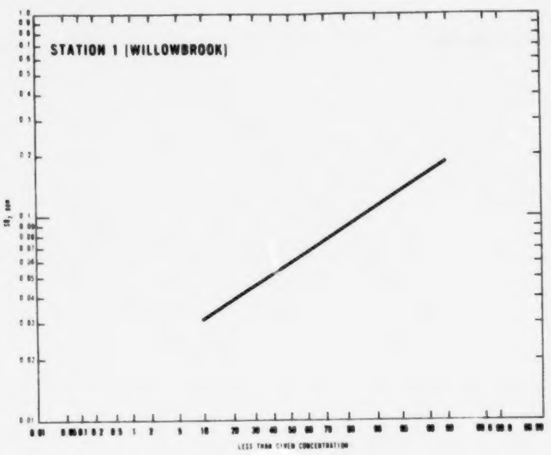


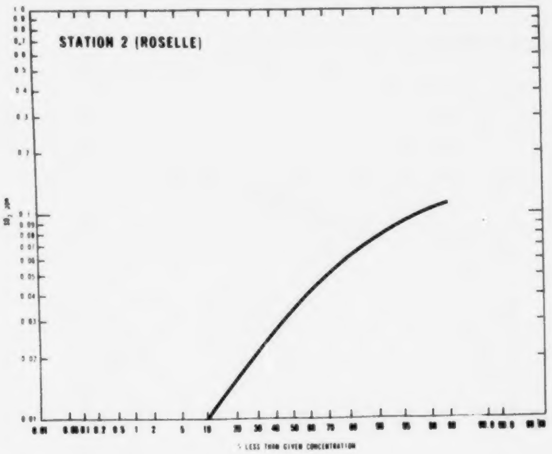
Cumulative frequency distribution of hourly sulfur dioxide concentrations during summer 1966.

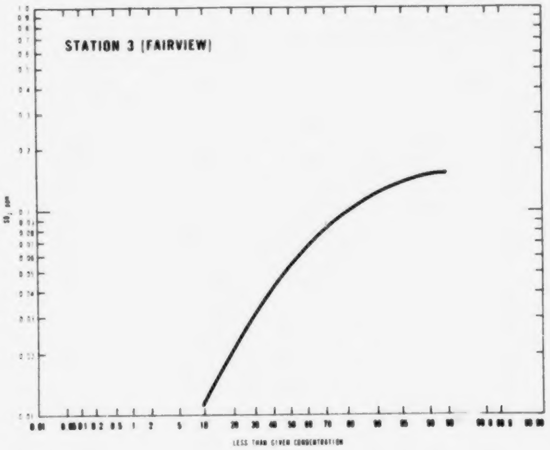
Reproduced from best available copy.

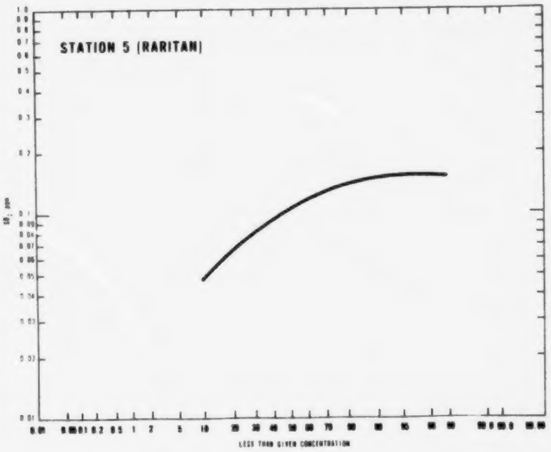


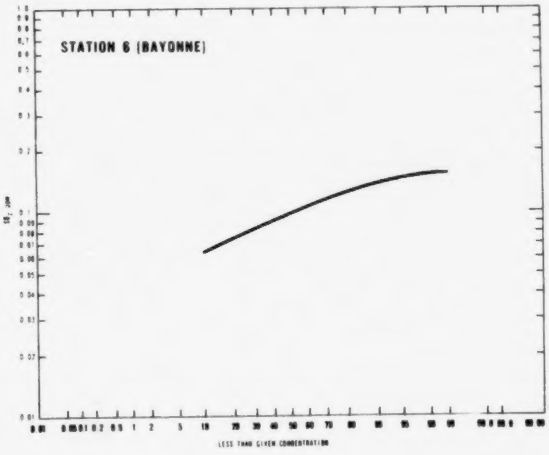
Cumulative frequency distribution of hourly sulfur dioxide concentrations during summer 1966.



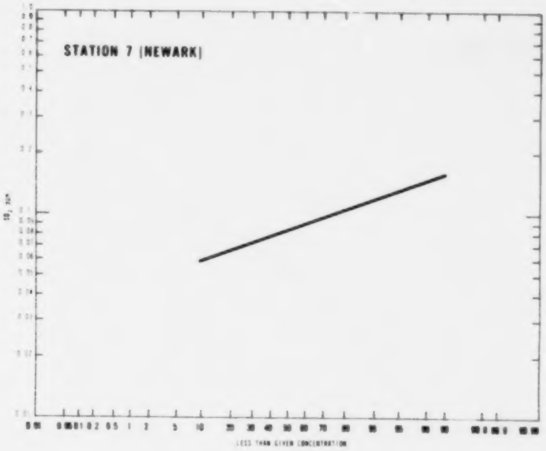


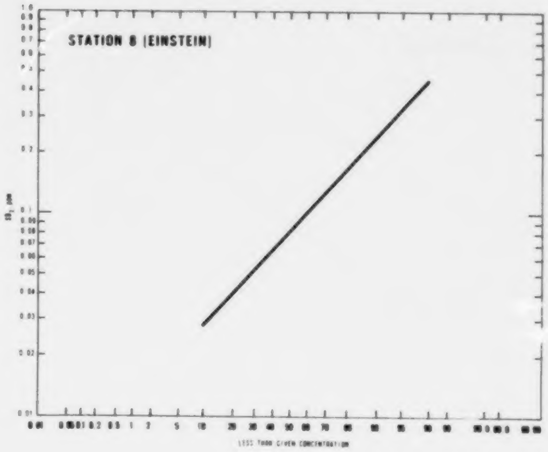


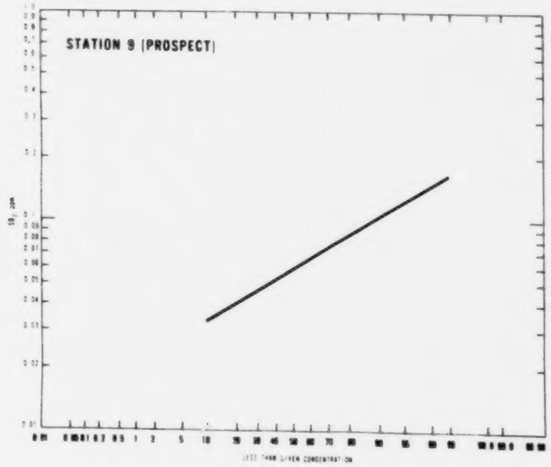


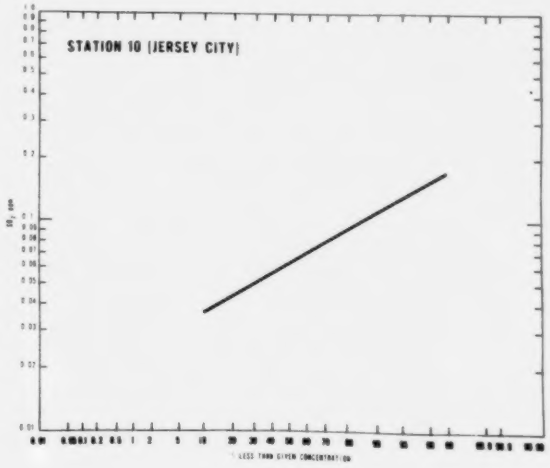


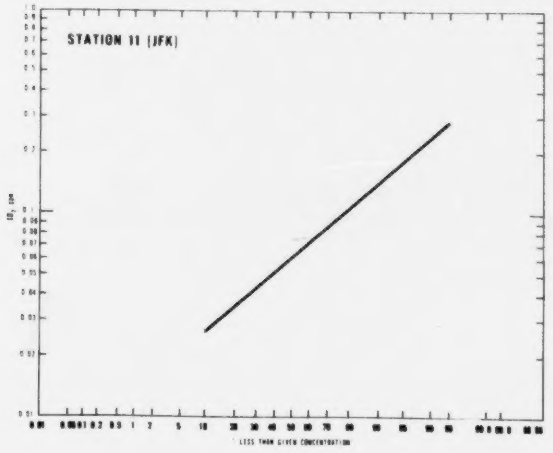
Cumulative frequency distribution of daily sulfur dioxide concentrations during summer 1966.



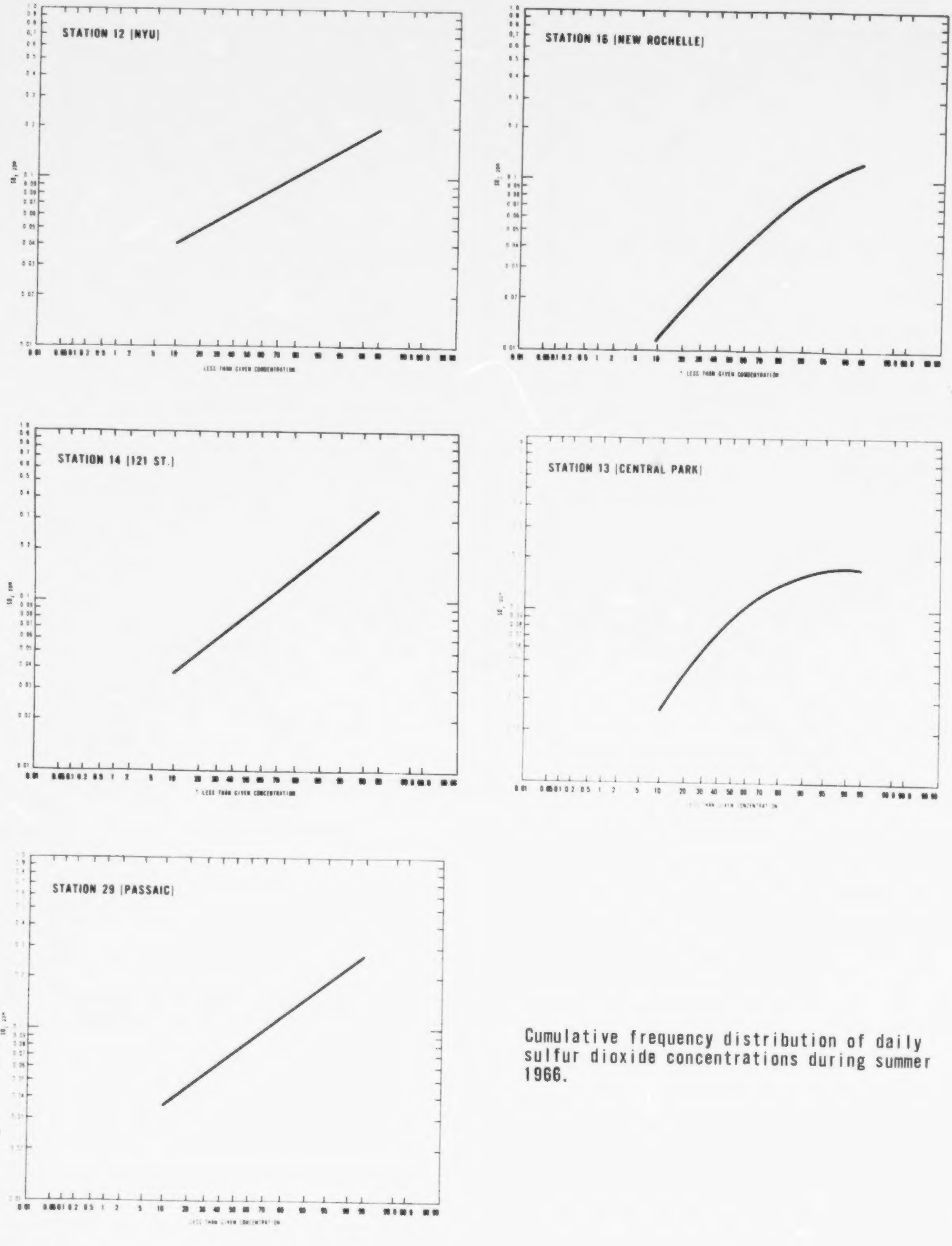




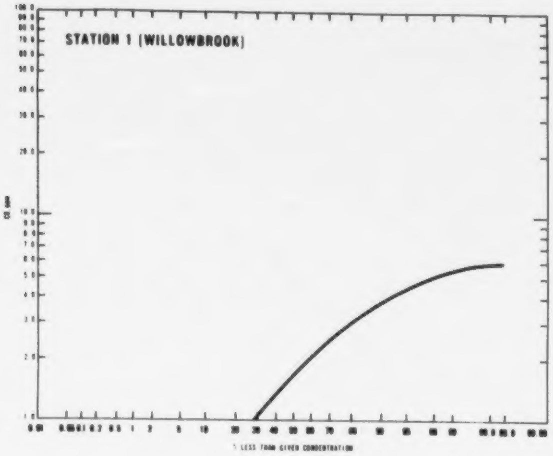


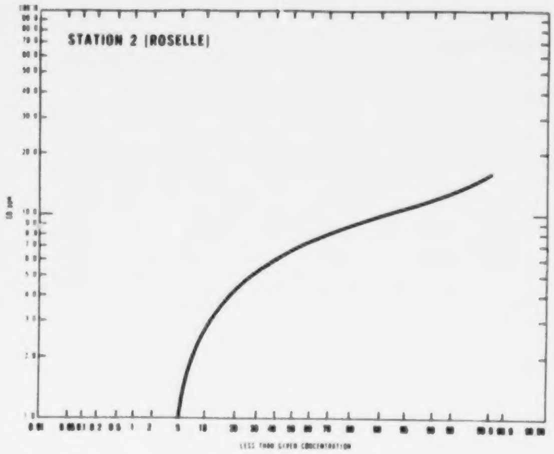


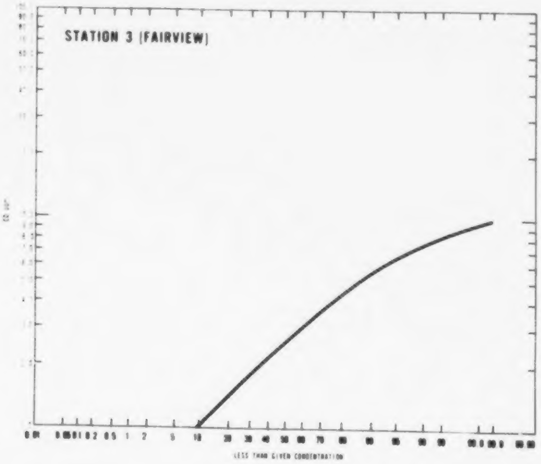
Cumulative frequency distribution of daily sulfur dioxide concentrations during summer 1966.

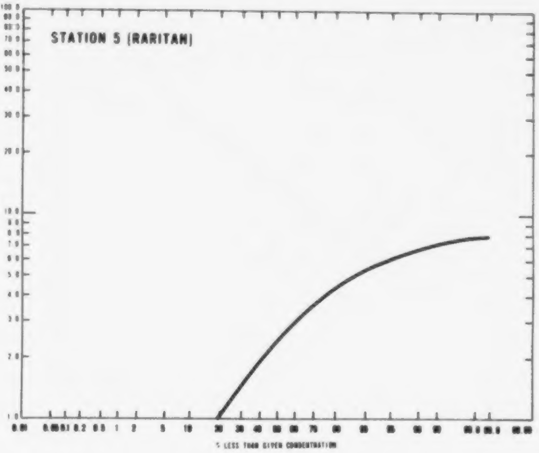


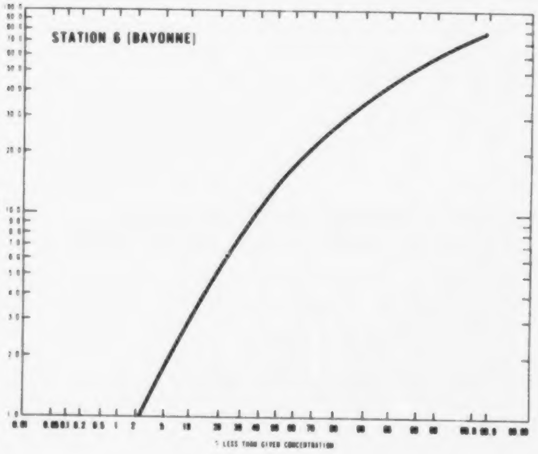
Cumulative frequency distribution of daily sulfur dioxide concentrations during summer 1966.



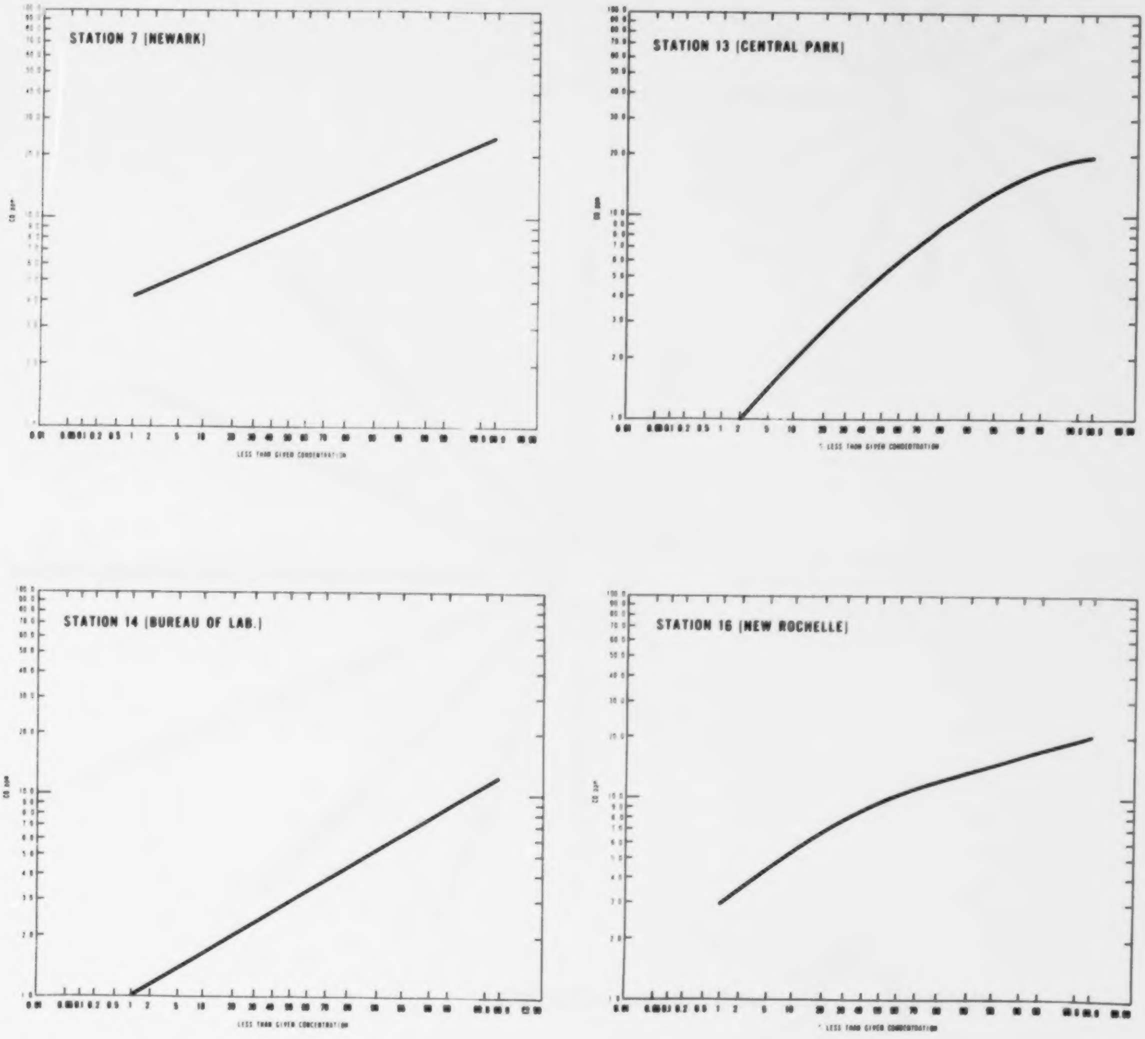




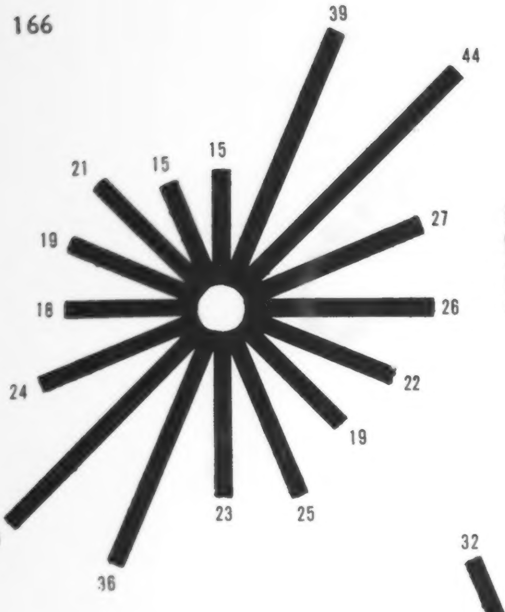




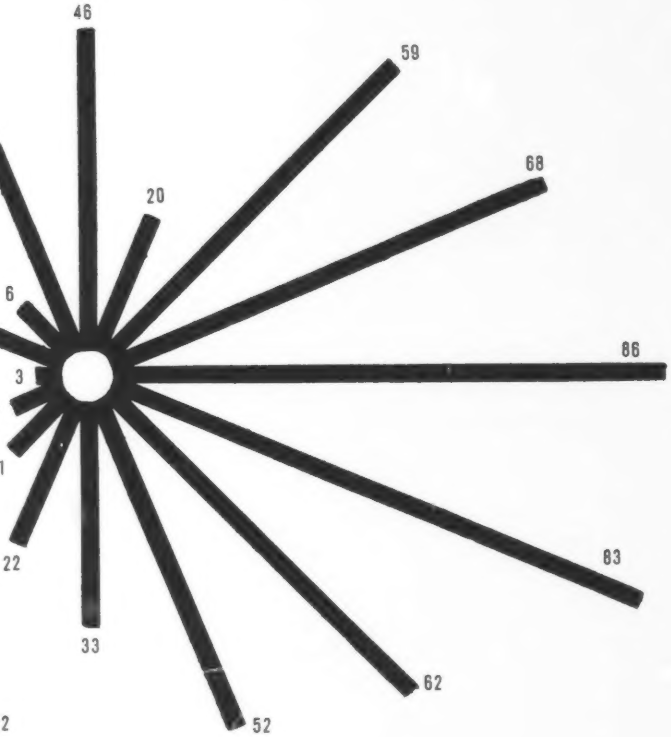
Cumulative frequency distribution of hourly carbon monoxide concentrations during summer 1966.



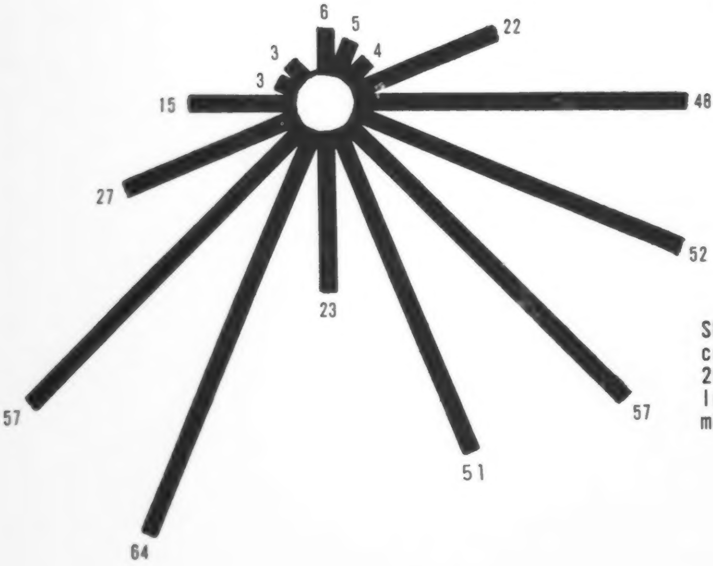
Cumulative frequency distribution of hourly carbon monoxide concentrations during summer 1966.



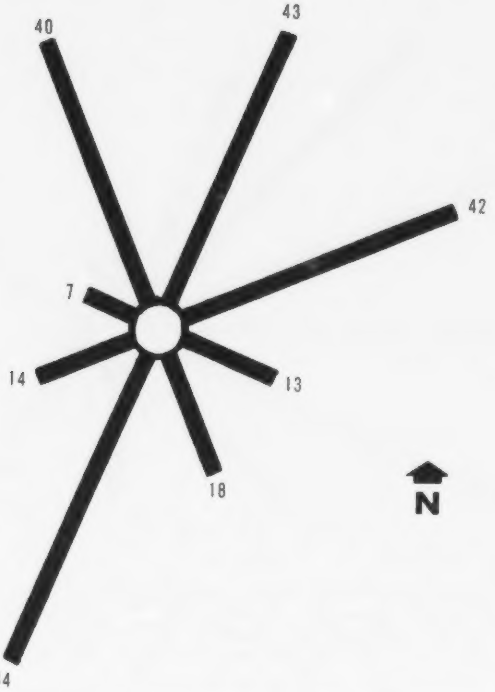
SO$_2$ pollution rose showing upper quartile concentrations (≥ 0.10 ppm; includes upper 27.6% of values)--air quality and meteorological data taken at Willowbrook during summer 1966.



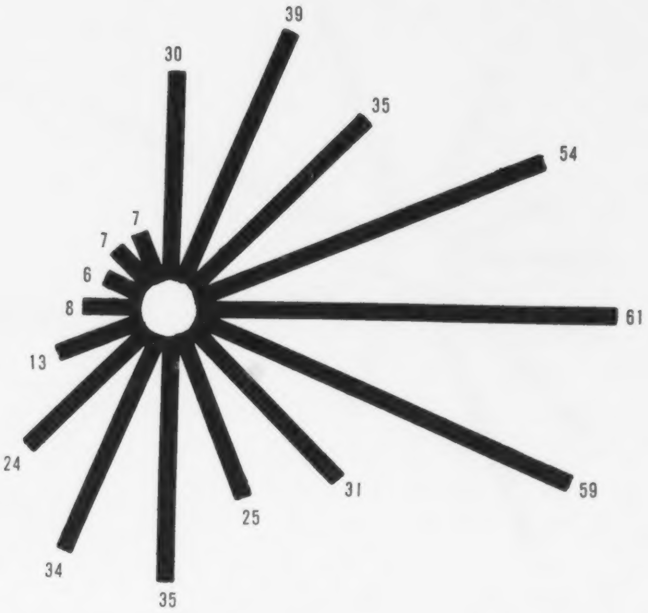
SO$_2$ pollution rose showing upper quartile concentrations (≥ 0.05 ppm; includes upper 30.2% of values)--air quality and meteorological data taken at Roselle during summer 1966.



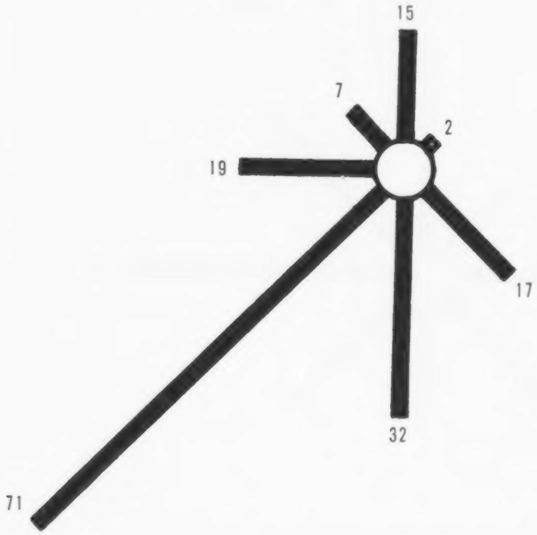
SO$_2$ pollution rose showing upper quartile concentrations (≥ 0.09 ppm; includes upper 26.3% of values)-- air quality and meteorological data taken at Fairview during summer 1966.



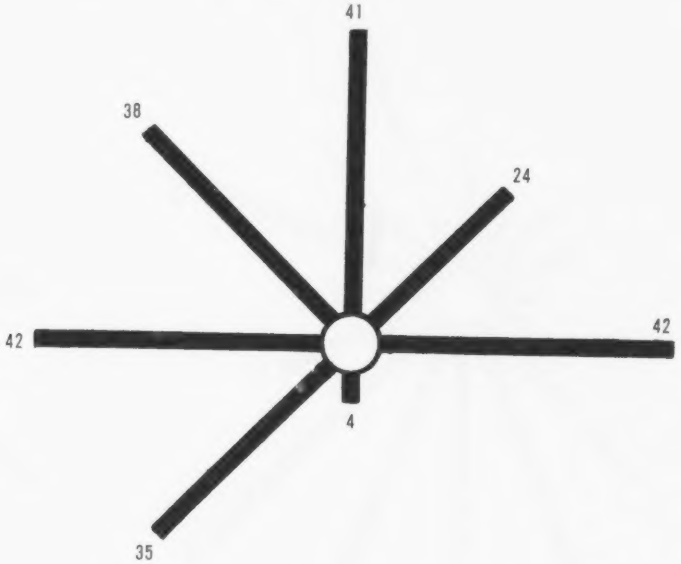
SO$_2$ pollution rose showing upper quartile concentrations ($\geq$0.12 ppm; includes upper 30.3% of values)--air quality and meteorological data taken at Bayonne during summer 1966.



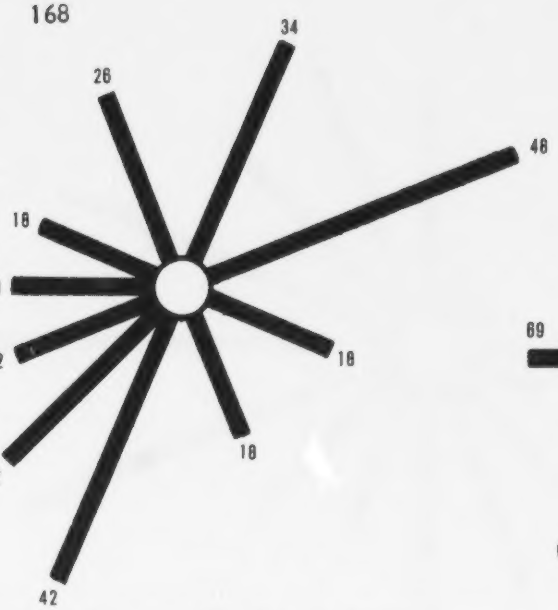
SO$_2$ pollution rose showing upper quartile concentrations ($\geq$0.11 ppm; includes upper 25.8% of values)--air quality data taken at Newark and meterological data at Newark Airport during summer 1966.



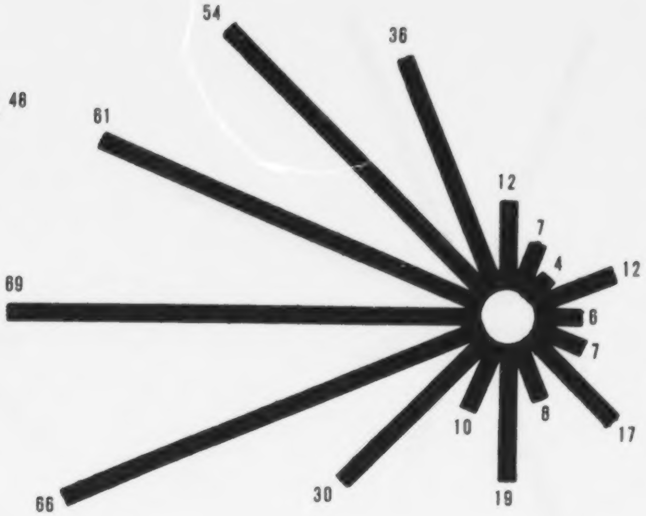
SO$_2$ pollution rose showing upper quartile concentrations ($\geq$0.18 ppm; includes upper 26.9% of values)--air quality data taken at NYU Einstein Medical College and meterological data at USWB LaGuardia Airport station during summer 1966.



SO$_2$ pollution rose showing upper quartile concentrations ($\geq$0.09 ppm; includes upper 28% of values)--air quality data taken by NYU at Prospect Park and meteorological data at USWB LaGuardia Airport station during summer 1966.



SO$_2$ pollution rose showing upper quartile concentrations ($\geq$ 0.09 ppm; includes upper 30.2% of values)--air quality data taken by NYU at Pollack Hospital and meteorological data at Bayonne during summer 1966.



SO$_2$ pollution rose showing upper quantile concentrations ($\geq$ 0.10 ppm; includes upper 27.5% of values)--air quality data taken by NYU at JFK International Airport and meteorological data by USWB at JFK International Airport station during summer 1966.

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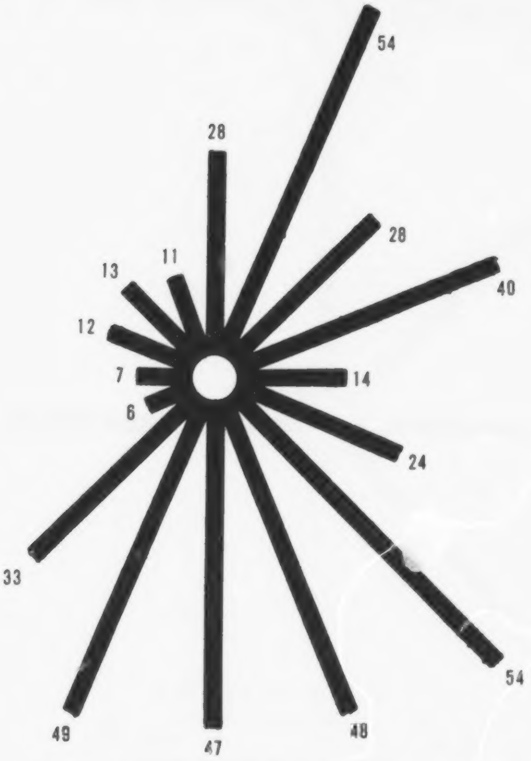
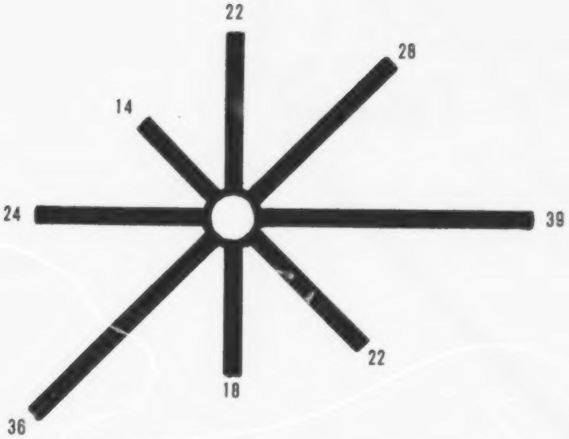
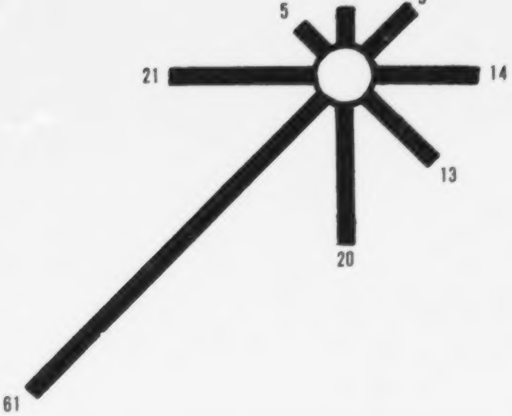


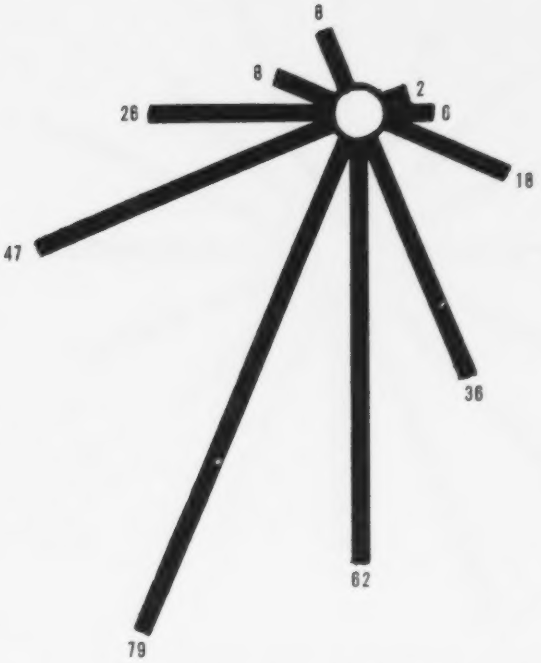
SO$_2$ pollution rose showing upper quartile concentrations ($\geq$ 0.11 ppm; includes upper 28.6% of values)--air quality and meteorological data taken by NYU at Bronx during summer 1966.



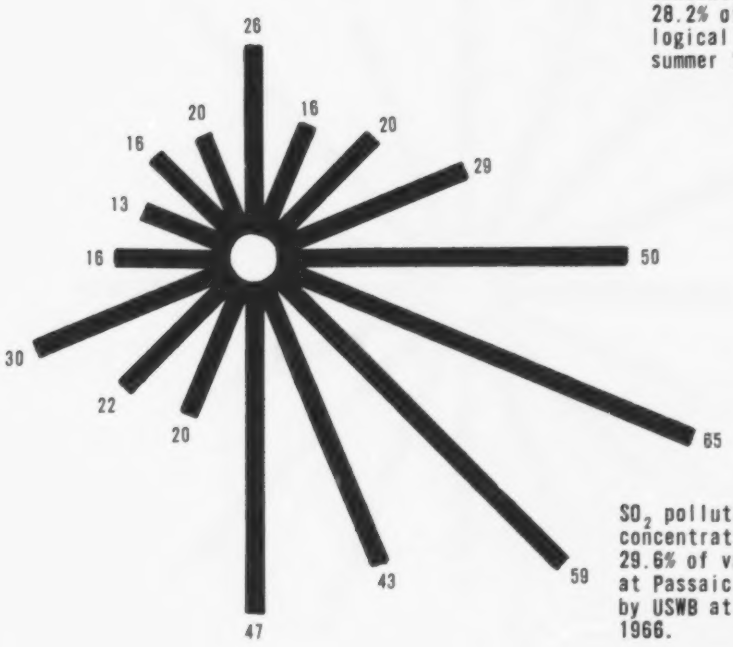
SO$_2$ pollution rose showing upper quartile concentrations ($\geq$ 0.13 ppm; includes upper 26.9% of values)--air quality and meteorological data taken at Central Park during summer 1966.



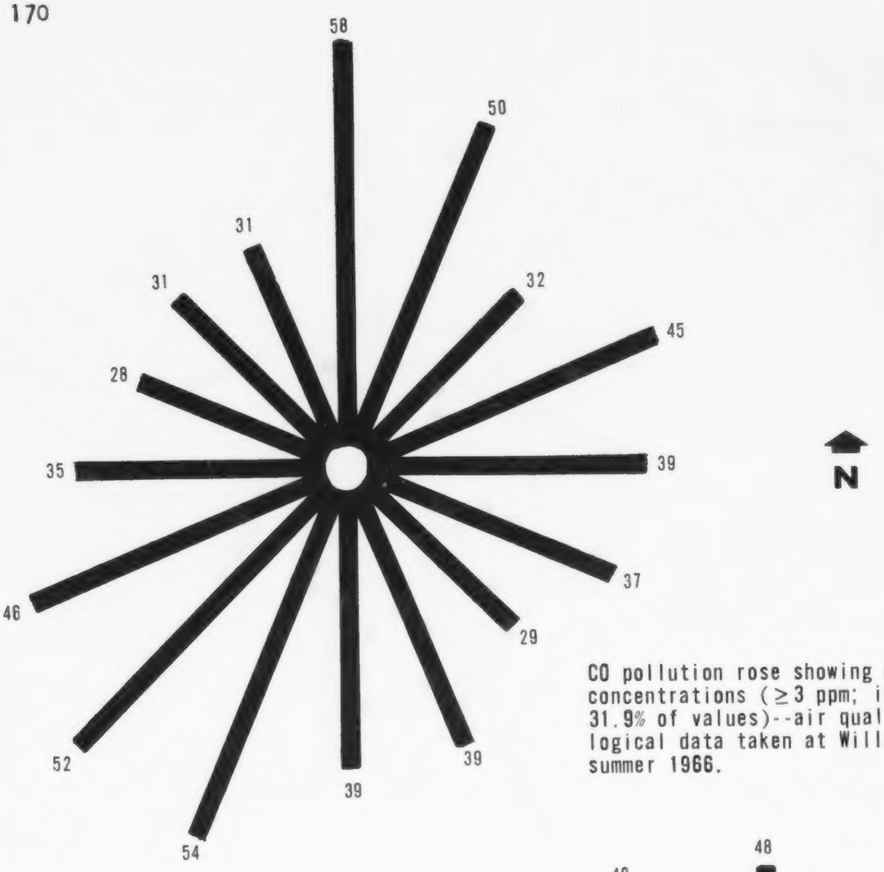
SO_2 pollution rose showing upper quartile concentrations ($\geq$ 0.13 ppm; includes upper 26.7% of values)--air quality data taken by Bureau of Laboratories at 121st Street and meteorological data taken at Central Park during summer 1966.



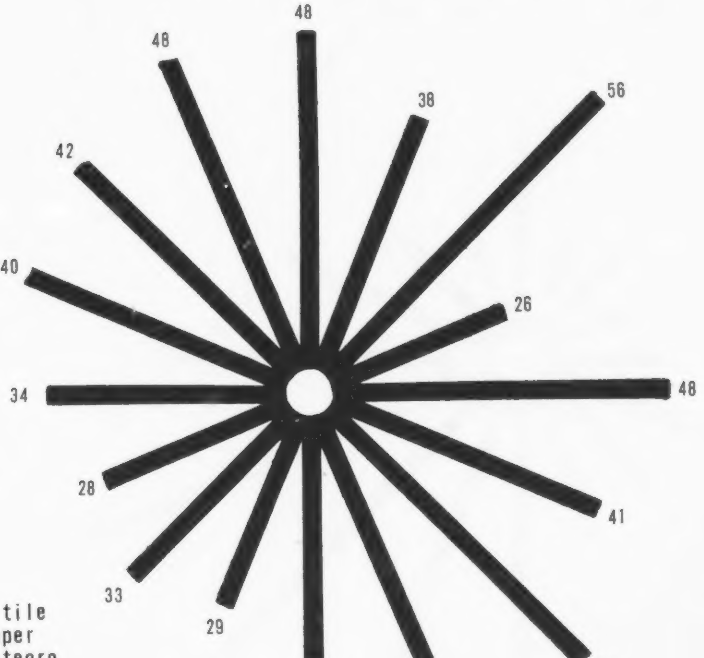
SO_2 pollution rose showing upper quartile concentrations ($\geq$ 0.05 ppm; includes upper 28.2% of values)--air quality and meteorological data taken at New Rochelle during summer 1966.



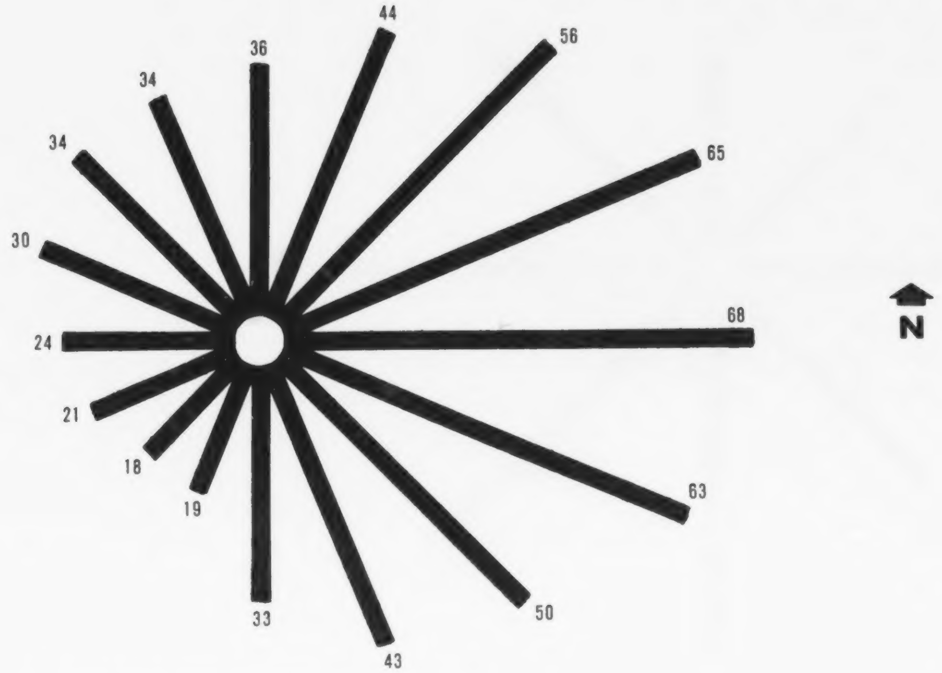
SO_2 pollution rose showing upper quartile concentrations ($\geq$ 0.12 ppm; includes upper 29.6% of values)--air quality data taken at Passaic and meteorological data taken by USWB at Teterboro Airport during summer 1966.



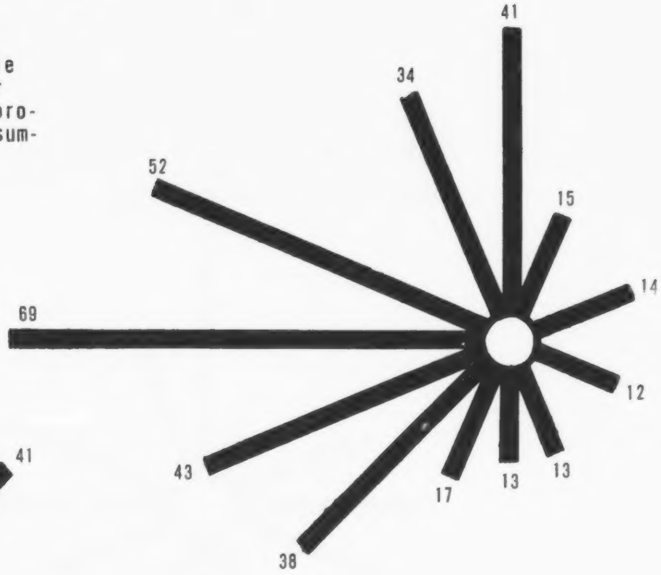
CO pollution rose showing upper quartile concentrations (≥ 3 ppm; includes upper 31.9% of values)--air quality and meteorological data taken at Willowbrook during summer 1966.



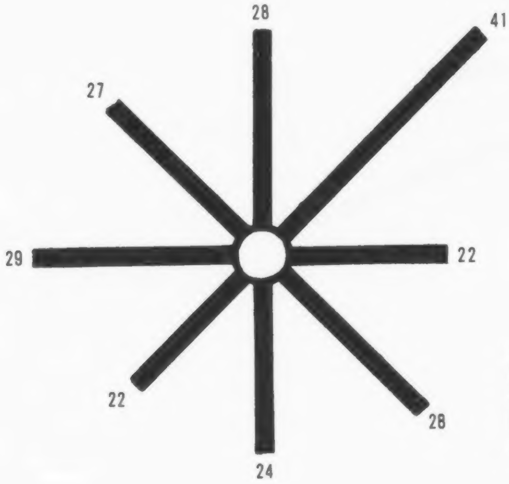
CO pollution rose showing upper quartile concentrations (≥ 8 ppm; includes upper 37.9% of values)--air quality and meteoro logical data taken at Roselle during summer 1966.



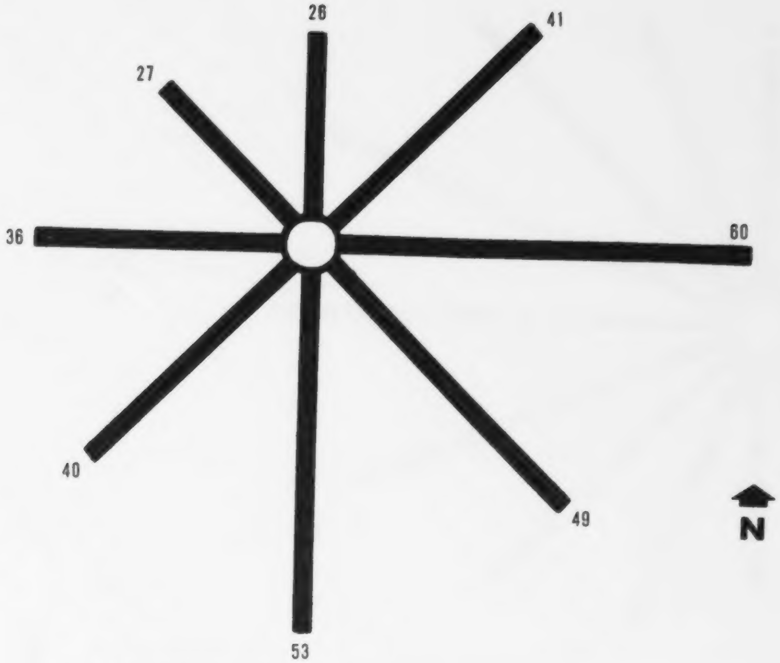
CO pollution rose showing upper quartile concentrations (≥ 4 ppm; includes upper 36.1% of values)--air quality and meteorological data taken at Fairview during summer 1966.



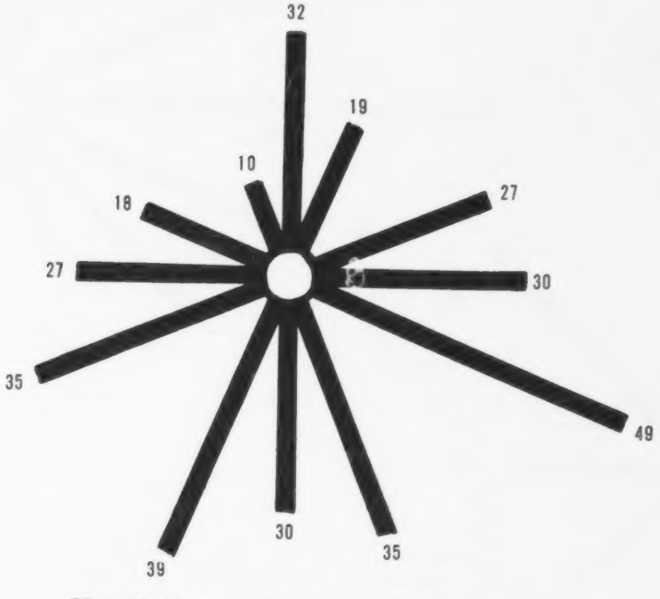
CO pollution rose showing upper quartile concentrations (≥ 13 ppm; includes upper 26% of values)--air quality data taken at Newark and meteorological data taken at Bayonne during summer 1966.



CO pollution rose showing upper quartile concentrations (≥ 8 ppm; includes upper 27.4% of values)--air quality and meteorological data taken at Central Park during summer 1966.



CO pollution rose showing upper quartile concentrations (≥ 3 ppm; includes upper 41.1% of values)--air quality data taken by Bureau of Laboratories at 121st Street and meteorological data taken at LaGuardia Airport during summer 1966.



CO pollution rose showing upper quartile concentrations (≥ 13 ppm; includes upper 31.1% of values)--air quality and meteorological data taken at New Rochelle during summer 1966